57.0 / 17

ADVERTISEMENT.

This volume forms the twenty-seventh of a series, composed of original memoirs on different branches of knowledge, published at the expense and under the direction of the Smithsonian Institution. The publication of this series forms part of a general plan adopted for carrying into effect the benevolent intentions of JAMES SMITHSON, Esq., of England. This gentleman left hi property in trust to the United States of America to found an institution which should bear his own name and have for "*increase* and *diffusion* of knowledge among men." This tru by the Government of the United States, and acts of Congre August 10, 1846, and March 12, 1894, constituting the Pres President, the Chief Justice of the United States, and the hea Departments an establishment under the name of the "SMI TUTION, FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMO members of this establishment may hold stated and special r supervision of the affairs of the Institution and for the advice of a Board of Regents to whom the financial and other affairs

The Board of Regents consists of two members *ex-officio* ment, namely, the Vice-President of the United States and tl of the United States, together with twelve other members, thi appointed from the Senate by its President, three from the l sentatives by the Speaker, and six persons appointed by a jo both Houses. To this board is given the power of electing other officers for conducting the active operations of the Institu

To carry into effect the purposes of the testator, the plan should evidently embrace two objects; one, the increase of k addition of new truths to the existing stock; the other, the dif edge, thus increased, among men. No restriction is made in fa of knowledge, and hence each branch is entitled to and should of attention.

The act of Congress establishing the Institution directs, plan of organization, the formation of a library, a museum, art, together with provisions for physical research and popula it leaves to the Regents the power of adopting such other parti tion as they may deem best suited to promote the objects of tl

After much deliberation, the Regents resolved to apportion the annual income specifically among the different objects and operations of the Institution in such manner as may, in the judgment of the Regents, be necessary and proper for each, according to its intrinsic importance, and a compliance in good faith with the law.

The following are the details of the two parts of the general plan of organization provisionally adopted at the meeting of the Regents December 8, 1847:

DETAILS OF THE FIRST PART OF THE PLAN.

To increase Knowledge.—*It is proposed to stimulate research by offering rewards for original memoirs on all subjects of investigation.*

The memoirs thus obtained to be published in a series of volumes, in a ..o form, and entitled "Smithsonian Contributions to Knowledge."

2. No memoir on subjects of physical science to be accepted for publication ..h does not furnish a positive addition to human knowledge, resting on ... research; and all unverified speculations to be rejected.

... memoir presented to the Institution to be submitted for examina- ...mmission of persons of reputation for learning in the branch to ...oir pertains, and to be accepted for publication only in case the ...commission is favorable.

...mission to be chosen by the officers of the Institution, and the ...or, as far as practicable, concealed, unless a favorable decision

...olumes of the memoirs to be exchanged for the transactions of ...scientific societies, and copies to be given to all the colleges and ...ries in this country. One part of the remaining copies may be ...sale, and the other carefully preserved to form complete sets of the ...pply the demand from new institutions.

...tract, or popular account, of the contents of these memoirs to be ...blic through the annual report of the Regents to Congress.

...e Knowledge.—*It is also proposed to appropriate a portion of ...e annually to special objects of research, under the direction of ...e persons.*

...he objects and the amount appropriated to be recommended by coun- ...he Institution.

...opriations in different years to different objects, so that in course ... branch of knowledge may receive a share.

3. The results obtained from these appropriations to be published, with the memoirs before mentioned, in the volumes of the Smithsonian Contributions to Knowledge.

4. Examples of objects for which appropriations may be made:

(1) System of extended meteorological observations for solving the problem of American storms.

(2) Explorations in descriptive natural history, and geological, mathematical, and topographical surveys, to collect material for the formation of a physical atlas of the United States.

(3) Solution of experimental problems, such as a new determination of the weight of the earth, of the velocity of electricity, and of light; chemical analyses of soils and plants; collection and publication of scientific facts, accumulated in the offices of Government.

(4) Institution of statistical inquiries with reference to physical, moral, and political subjects.

(5) Historical researches and accurate surveys of places celebrated in American history.

(6) Ethnological researches, particularly with reference to the different races of men in North America; also explorations and accurate surveys of the mounds and other remains of the ancient people of our country.

I. To diffuse Knowledge.—*It is proposed to publish a series of reports, giving an account of the new discoveries in science, and of the changes made from year to year in all branches of knowledge not strictly professional.*

1. Some of these reports may be published annually, others at longer intervals, as the income of the Institution or the changes in the branches of knowledge may indicate.

2. The reports are to be prepared by collaborators eminent in the different branches of knowledge.

3. Each collaborator to be furnished with the journals and publications, domestic and foreign, necessary to the compilation of his report; to be paid a certain sum for his labors, and to be named on the title-page of the report.

4. The reports to be published in separate parts, so that persons interested in a particular branch can procure the parts relating to it without purchasing the whole.

5. These reports may be presented to Congress for partial distribution, the remaining copies to be given to literary and scientific institutions and sold to individuals for a moderate price.

The following are some of the subjects which may be embraced in the reports:

I. PHYSICAL CLASS.

1. Physics, including astronomy, natural philosophy, chemistry and meteorology.
2. Natural history, including botany, zoology, geology, etc.
3. Agriculture.
4. Application of science to arts.

II. MORAL AND POLITICAL CLASS.

5. Ethnology, including particular history, comparative philology, antiquities, etc.
6. Statistics and political economy.
7. Mental and moral philosophy.
8. A survey of the political events of the world; penal reform, etc.

III. LITERATURE AND THE FINE ARTS.

9. Modern literature.
10. The fine arts, and their application to the useful arts.
11. Bibliography.
12. Obituary notices of distinguished individuals.

II. To DIFFUSE KNOWLEDGE.—*It is proposed to publish occasionally separate treatises on subjects of general interest.*

1. These treatises may occasionally consist of valuable memoirs translated from foreign languages, or of articles prepared under the direction of the Institution, or procured by offering premiums for the best exposition of a given subject.
2. The treatises to be submitted to a commission of competent judges previous to their publication.

DETAILS OF THE SECOND PART OF THE PLAN OF ORGANIZATION.

This part contemplates the formation of a library, a museum, and a gallery of art.

1. To carry out the plan before described a library will be required consisting, first, of a complete collection of the transactions and proceedings of all the learned societies of the world; second, of the more important current periodical publications and other works necessary in preparing the periodical reports.

2. The Institution should make special collections particularly of objects to illustrate and verify its own publications; also a collection of instruments of research in all branchés of experimental science.

3. With reference to the collection of books other than those mentioned above, catalogues of all the different libraries in the United States should be procured, in order that the valuable books first purchased may be such as are not to be found elsewhere in the United States.

4. Also catalogues of memoirs and of books in foreign libraries and other materials should be collected, for rendering the Institution a center of bibliographical knowledge, whence the student may be directed to any work which he may require.

5. It is believed that the collections in natural history will increase by donation as rapidly as the income of the Institution can make provision for their reception, and therefore it will seldom be necessary to purchase any article of this kind.

6. Attempts should be made to procure for the gallery of art casts of the most celebrated articles of ancient and modern sculpture.

7. The arts may be encouraged by providing a room, free of expense, for the exhibition of the objects of the Art Union and other similar societies.

8. A small appropriation should annually be made for models of antiquities, such as those of the remains of ancient temples, etc.

9. The Secretary and his assistants, during the session of Congress, will be required to illustrate new discoveries in science and to exhibit new objects of art. Distinguished individuals should also be invited to give lectures on subjects of general interest.

In accordance with the rules adopted in the programme of organization, each memoir in this volume has been favorably reported on by a commission appointed for its examination. It is, however, impossible, in most cases, to verify the statements of an author, and therefore neither the commission nor the Institution can be responsible for more than the general character of a memoir.

OFFICERS

OF THE

SMITHSONIAN INSTITUTION.

WILLIAM H. TAFT,

PRESIDENT OF THE UNITED STATES,

EX OFFICIO PRESIDING OFFICER OF THE INSTITUTION.

JAMES S. SHERMAN,

VICE-PRESIDENT OF THE UNITED STATES,

CHANCELLOR OF THE INSTITUTION.

CHARLES D. WALCOTT,

SECRETARY OF THE INSTITUTION.

RICHARD RATHBUN,

ASSISTANT SECRETARY IN CHARGE OF NATIONAL MUSEUM.

FREDERICK W. TRUE,

ASSISTANT SECRETARY IN CHARGE OF LIBRARY AND EXCHANGES.

MEMBERS EX OFFICIO OF THE INSTITUTION.

William H. Taft	*President of the United States.*
James S. Sherman	*Vice-President of the United States.*
Edward Douglass White	*Chief Justice of the United States.*
Philander C. Knox	*Secretary of State.*
Franklin MacVeagh	*Secretary of the Treasury.*
Henry L. Stimson	*Secretary of War.*
George W. Wickersham	*Attorney-General.*
Frank H. Hitchcock	*Postmaster-General.*
George von L. Meyer	*Secretary of the Navy.*
Walter L. Fisher	*Secretary of the Interior.*
James Wilson	*Secretary of Agriculture.*
Charles Nagel	*Secretary of Commerce and Labor.*

REGENTS.

James S. Sherman .... *Vice-President of the United States, Chancellor.*

Edward Douglass White ...... *Chief Justice of the United States.*

Shelby M. Cullom .... *Member of the Senate.*

Henry Cabot Lodge .... *Member of the Senate.*

Augustus O. Bacon .... *Member of the Senate.*

John Dalzell .... *Member of the House of Representatives.*

James R. Mann .... *Member of the House of Representatives.*

William M. Howard .... *Member of the House of Representatives.*

James B. Angell .... *Citizen of Michigan.*

Andrew D. White .... *Citizen of New York.*

John B. Henderson, Jr. .... *Citizen of Washington, D. C.*

Alexander Graham Bell ...... *Citizen of Washington, D. C.*

George Gray .... *Citizen of Delaware.*

Charles F. Choate, Jr. .... *Citizen of Massachusetts.*

CONTENTS.

one minute, but as the power was in fact expended in 1/20 of that time we have $20 \times 0.00145 = 0.029$; that is, during the brief flight, about 0.03 of a horse-power was exerted, and this sustained a total weight of only about a pound.

In comparing this flight with the ideal conditions of horizontal flight in "Aerodynamics," it will be remembered that this model's flight was so irregular and so far from horizontal, that in one case it flew up and struck the lofty ceiling. The angle with the horizon is, of course, so variable as to be practically unknown, and therefore no direct comparison can be instituted with the data given on page 107 of "Experiments in Aerodynamics," but we find from these that at the lowest speed there given of about 35 feet per second, 0.03 of a horse-power exerted for three seconds would carry nearly one pound through a distance of somewhat over 100 feet in horizontal flight.

The number of turns of the propellers multiplied by the pitch corresponds to a flight of about 16 metres, while the mean actual flight was about 12. It is probable, however, that there was really more slip than this part of the observation would indicate. It was also observed that there seemed to be very little additional compensatory gain in the steering of No. 30 for the weight of the long rudder-tail it carried. It may be remarked that in subsequent observations the superiority of the curved wing in lifting power was confirmed, though it was found more liable to accident than the flatter one, tending to turn the model over unless it was very carefully adjusted.

It may also be observed that these and subsequent observations show, as might have been anticipated, that as the motor power increased, the necessary wing surface diminished, but that it was in general an easier and more efficient employment of power to carry a surface of four feet sustaining area to the pound than one of three, while one of two feet to the pound was nearly the limit that could be used with the rubber motor.[10]

It may be remarked that the flights this day, reckoned in horizontal distance, were exceptionally short, but that the best flights at other times obtained with these models (30 and 31) did not exceed 25 metres. Such observations were continued in hundreds of trials, without any much more conclusive results.

[10] Observers following de Lucy have long since called attention to the fact that as the scale of
the size of the sustaining surfaces diminishes relatively to the weight
Nature's flying things increases,
sustained. M. Harting (Aeronautical Society, 1870) has shown that the relation $\frac{\sqrt{\text{area}}}{\sqrt[3]{\text{weight}}}$ is sur-
prisingly constant when bats varying in weight as much as 250 times are the subject of experiment,
and later observations by Marey have not materially affected the statement. As to the muscular power
which Nature has imparted with the greater or lesser weight, this varies, decreasing very rapidly as
the weight increases. The same remark may be made, apparently with at least approximate truth,
with regard to the soaring bird, and the important inference is that if there be any analogy between
the bird and the aerodrome, as the scale of the construction of the latter increases, it may be reason-
ably anticipated that the size of the sustaining surfaces will relatively diminish rather than increase.
We may conveniently use M. Harting's formula in the form $a = n^2 w^{\frac{2}{3}} = \frac{l^2}{m^2}$ where a = area in sq.
cm., w the weight in grammes, l the length of the wing in cm., n and m constants derived from
observation.

The final results, then, of the observations with rubber-driven models (which were commenced as early as 1887, continued actively through the greater portion of the year 1891 and resumed, as will be seen later, even as late as 1895), were not such as to give information proportioned to their trouble and cost, and it was decided to commence experiments with a steam-driven aerodrome on a large scale.

CHAPTER III

AVAILABLE MOTORS

In the introductory chapter to "Experiments in Aerodynamics," it was asserted that

"These researches have led to the result that mechanical sustentation of heavy bodies in the air, combined with very great speeds, is not only possible, but within the reach of mechanical means we actually possess."

It was, however, necessary to make a proper selection in order to secure that source of power which is best adapted to the requirements of mechanical flight. Pénaud had used india rubber as the cheapest and at the same time the most available motor for the toys with which he was experimenting, but when models were constructed that were heavier than anything made prior to 1887, it appeared, after the exhaustive trials with rubber referred to in the preceding chapter, that something which could give longer and steadier flights must be used as a motor, even for the preliminary trials, and the construction of the large steam-driven model known as No. 0, and elsewhere described, was begun. Even before the completion of this, the probability of its failure grew so strong that experiments were commenced with other motors, which it was hoped might be consistent with a lighter construction.

These experiments which commenced in the spring of 1892 and continued for nearly a twelvemonth, were made upon the use of compressed air, carbonic-acid gas, electricity in primary and storage batteries, and numerous other contrivances, with the result that the steam engine was finally returned to, as being the only one that gave any promise of immediate success in supporting a machine which would teach the conditions of flight by actual trial, though it may be added that the gas engine which was not tried at this time on account of engineering difficulties, was regarded from the first as being the best in theory and likely to be ultimately resorted to. All others were fundamentally too heavy, and weight was always the greatest enemy.

It is the purpose of this chapter to pass in brief review the work that was done and the amount of energy that was obtained with these several types of motors, as well as the obstacles which they presented to practical application upon working aerodromes.

India Rubber

India rubber is the source of power to which the designer of a working model naturally turns, where it is desirable that it shall be, above all, light and free from the necessity of using complicated mechanism. Rubber motors were,

therefore, used on all of the earlier models, and served as the basis of calculations made to determine the amount of power that would be required to propel aerodromes with other sources of energy.

Some of the disadvantages inherent in the use of rubber are at once apparent, such as the limited time during which its action is available, the small total amount of power, and the variability in the amount of power put forth in a unit of time between the moment of release and the exhaustion of the power. In addition, serious, though less obvious difficulties, present themselves in practice.

There are two ways in which rubber can be used; one by twisting a hank of strands, and, while one end is held fast, allowing the other to revolve; the other, by a direct longitudinal stretching of the rubber, one end being held fast and the other attached to the moving parts of the mechanism. The former method was adopted by Pénaud, and was also used in all of my early constructions, but while it is most convenient and simple in its (theoretical) application, it has, in addition to the above drawbacks, that of knotting or kinking, when wound too many turns, in such a way as to cause friction on any containing tube not made impracticably large, and also that of unwinding so irregularly as to make the result of one experiment useless for comparison with another.

In 1895, some experiments were made in which the latter method was used, but this was found to involve an almost impracticable weight, because of the frame (which must be strong enough to withstand the end pull of the rubber) and the mechanism needed to convert the pull into a movement of rotation.

As the power put forth in a unit of time varies, so there is a corresponding variation according to the original tension to which the rubber is subjected. Thus in some experiments made in 1889 with a six-bladed propeller 18.8 inches in diameter, driven by a rubber spring 1.3 inches wide, 0.12 inch thick and 3 feet long, doubled, and weighing 0.38 pound, the following results were obtained:

Number of twists of rubber........	50	75	100
Time required to run down.........	7 sec.	10 sec.	12 sec.
Foot-pounds developed	37.5	63.0	124.6
Foot-pounds developed per min.....	321.4	378.0	623.0
Horse-power developed	0.0097	0.0115	0.0189

Thus we see that, with twice the number of turns, more than three times the amount of work was done and almost twice the amount of power developed, giving as a maximum for this particular instance 328 foot-pounds per pound of rubber.

The usual method of employing the twisted rubber was to use a number of fine strands formed into a hank looped at each end. One of these hanks, consisting of 162 single or 81 double strands of rubber, and weighing 73 grammes, when given 51 turns developed 55 foot-pounds of work, which was put out in 4 seconds. This corresponds to 0.01 horse-power per minute for one pound of rubber.

The results of a large number of tests show that one pound of twisted rubber can put forth from 450 to 500 or more foot-pounds of work, but at the cost of an overstrain, and that a safe working factor can hardly be taken at higher than 300 foot-pounds, if we are to avoid the "fatigue" of the rubber, which otherwise becomes as marked as that of a human muscle.

While twisting is an exceedingly convenient form of application of the resilience of rubber to the turning of propelling wheels, the direct stretch is, as has been remarked, much more efficient in foot-pounds of energy developed by the same weight of rubber. It was found that rubber could not, without undue "fatigue," be stretched to more than four and a half times its original length, though experiments were made to determine the amount of work that a rubber band, weighing one pound, was capable of doing, the stretching being carried to seven times its original length. The results varied with the rubber used and the conditions of temperature under which the experiments were tried, ranging from 1543 foot-pounds to 2600 foot-pounds. The tests led to the conclusion that, for average working, one pound of rubber so stretched, is capable of doing 2000 foot-pounds of work, but, owing to the weight of the supporting frame and of the mechanism, this result can be obtained only under conditions impracticable for a flying machine. In the more practicable twisted form it furnishes, as has been said, less than a fifth of that amount.

The conclusions reached from these experiments are:

1. The length of the unstretched rubber remaining the same, the sustaining power will be directly proportional to the weight of rubber;

2. With a given weight of rubber, the end strain is inversely proportional to the length of the unstretched rubber;

3. With a given weight of rubber, the work done is constant, whatever the form; hence if we let w=the work in foot-pounds, g=the weight of the rubber in pounds, and k=a constant taken at 2000 as given above, we have

$$w=kg=2000\ g \text{ foot-pounds.}$$

This is for an extension of seven units of length, so that for a unit of extension we would have approximately

$$w=300\ g \text{ foot-pounds}$$

which for four units of extension corresponds very closely to the 1300 foot-pounds which Pénaud claims to have obtained.

4. The end strain varies with the cross-section for a given unit of extension.

These results can lead to but one conclusion; that for the development of the same amount of power when that amount shall be 1 horse-power or more, rubber weighs enormously more than a steam engine, besides being less reliable

for a sustained effort, and, therefore, cannot be used for propelling aerodromes intended for a flight that is to be prolonged beyond a few seconds.[1]

It may be desirable to present a tabular view of the *theoretical* energy of available motors, which it will be noticed is a wholly different thing from the results obtained in practice. Thus, we represent the weight of rubber only, without regard to the weight of the frame required to hold it. In the steam engine, we consider the theoretical efficiency per pound of fuel, without regarding the enormous waste of weight in water in such small engines as these, or the weight of the engine itself. We treat the hot-water engine in like manner, and in regard to carbonic acid and compressed air, we take no note of the weight of the containing vessel, or of the cylinders and moving parts. In the same way we have the theoretical potency of electricity in primary and storage batteries, without counting the weight of the necessary electromotors; and of the inertia-engine without discussing that of the mechanism needed to transmit its power.

Foot-pounds of energy in one pound of

Gasoline	15,625,280
Alcohol	9,721,806
Gunpowder	960,000
Hot water, under pressure of 100 atmospheres	383,712
Air, under pressure of 100 atmospheres, isothermal expansion	120,584
Liquid carbonic acid, at temperature of 30° and pressure of 100 atmospheres	78,800
Electric battery; short-lived, thin walled; chromic acid and platinum	75,000
Steel ring, 8 inches in diameter, at speed of 3000 turns per minute	19,000
Storage battery	17,560
Rubber, pulled	2,000
Rubber, twisted	300

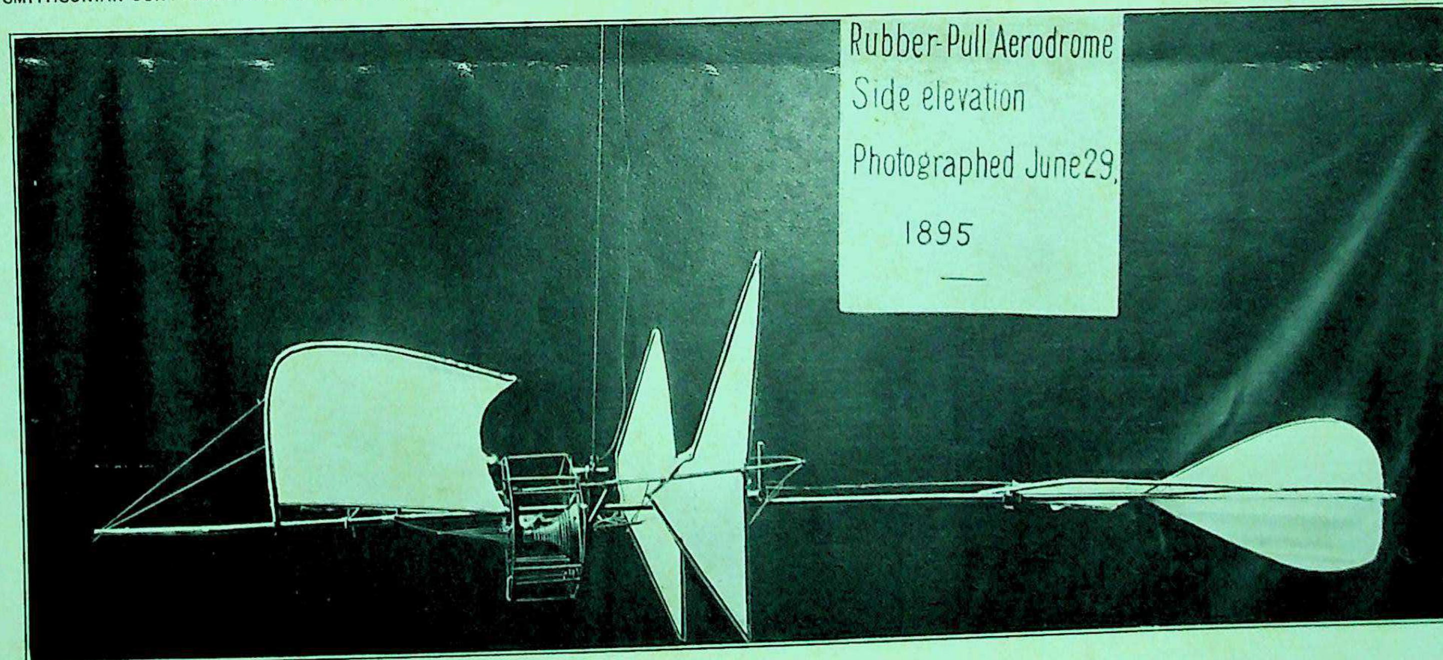
It may be interesting to consider next, in even a roughly approximate way, what may be expected from these various sources of energy in practice.

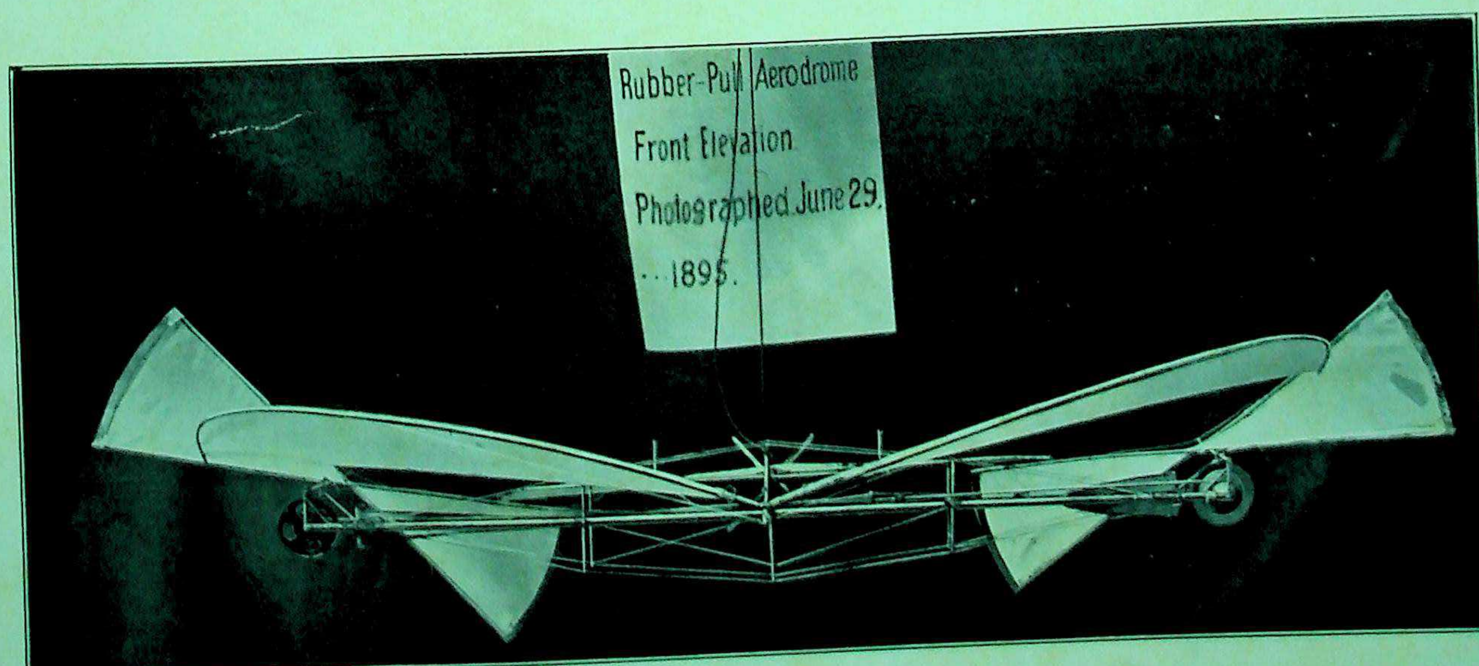
Steam Engine

The steam engine on a small scale, and under the actual restrictions of the model, must necessarily be extremely wasteful of power. If we suppose it to realize 2 per cent of the theoretical energy contained in the fuel, we shall be assuming more than was actually obtained. The energy of the fuel cannot be obtained at all, of course, without boiler and engine, whose weight, for the purpose of the following calculation, must be added to that of the fuel; and if we suppose the weight of the boilers, engines and water, for a single minute's flight, to be collectively ten pounds, we shall take an optimistic view of what may be expected under ordinary conditions. We have in this view 1/500 of the theo-

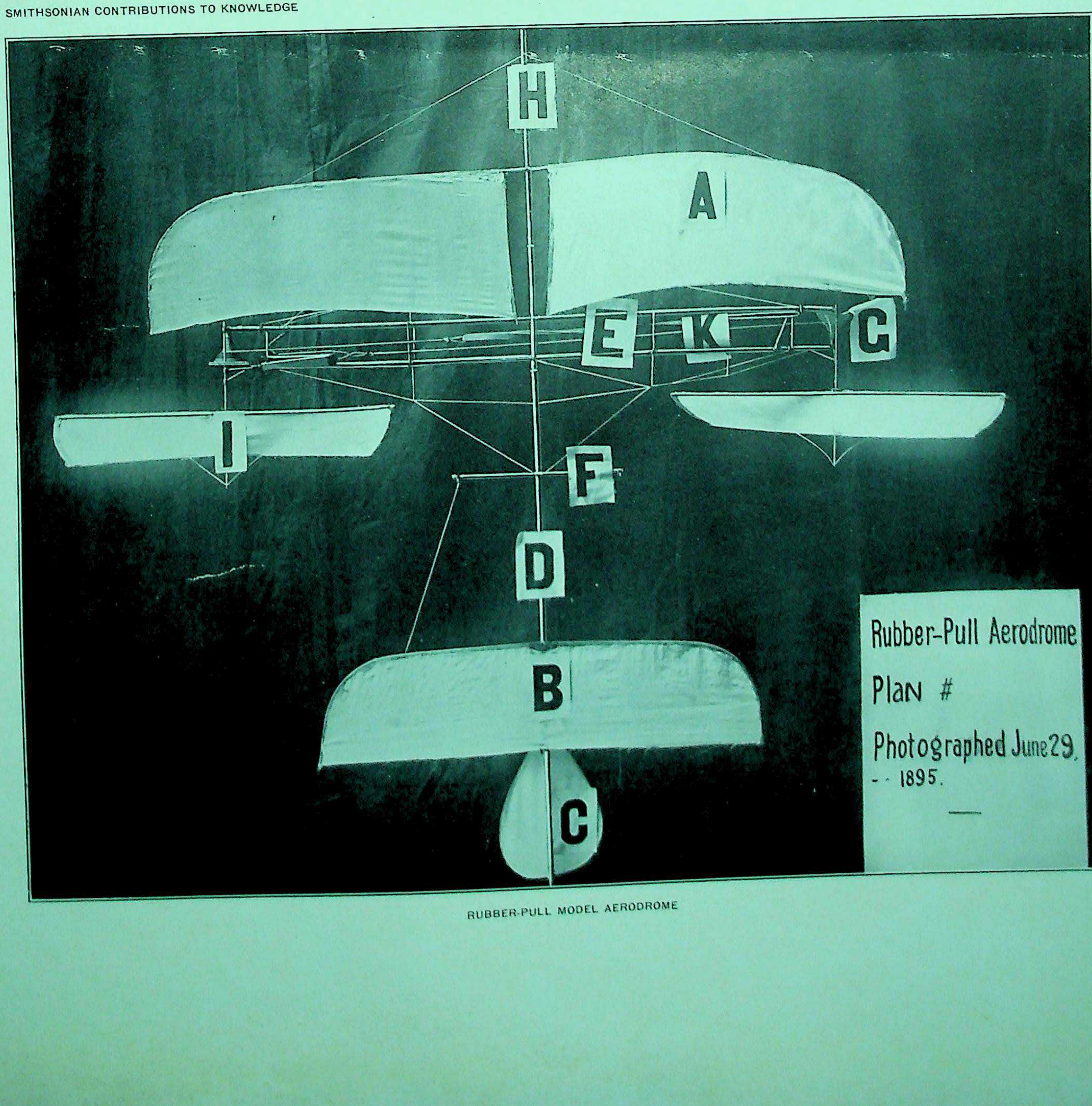
[1] A singular fact connected with the stretching of rubber is that the extension is not only not directly proportional to the power producing it, but that up to a certain limit it increases more rapidly than the power, and after this the relation becomes for a time more nearly constant, and after this again the extension becomes less and less in proportion.

In other words, if a curve be constructed whose abscissae represent extensions, and ordinates the corresponding weights, it will show a reverse curvature, one portion being concave toward the axis of abscissae, the other convex.

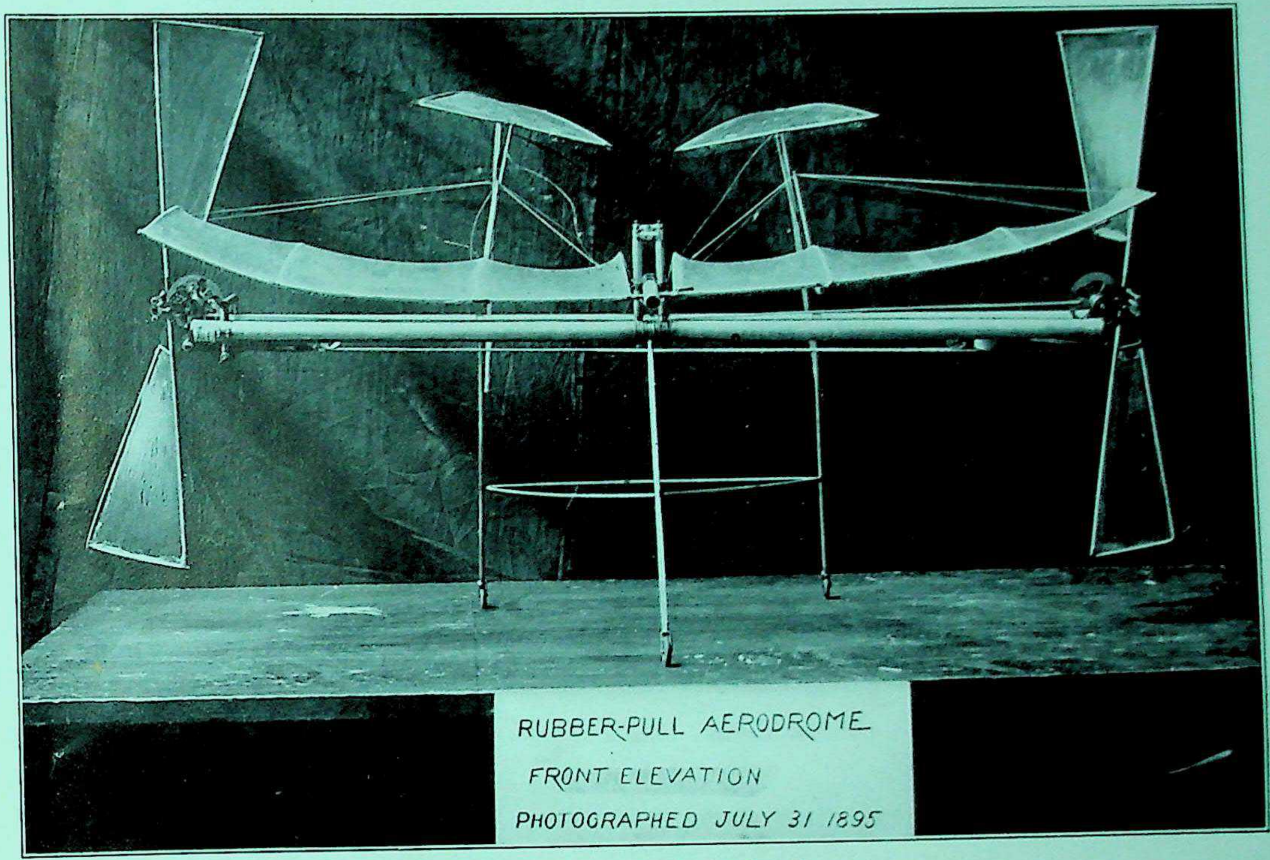




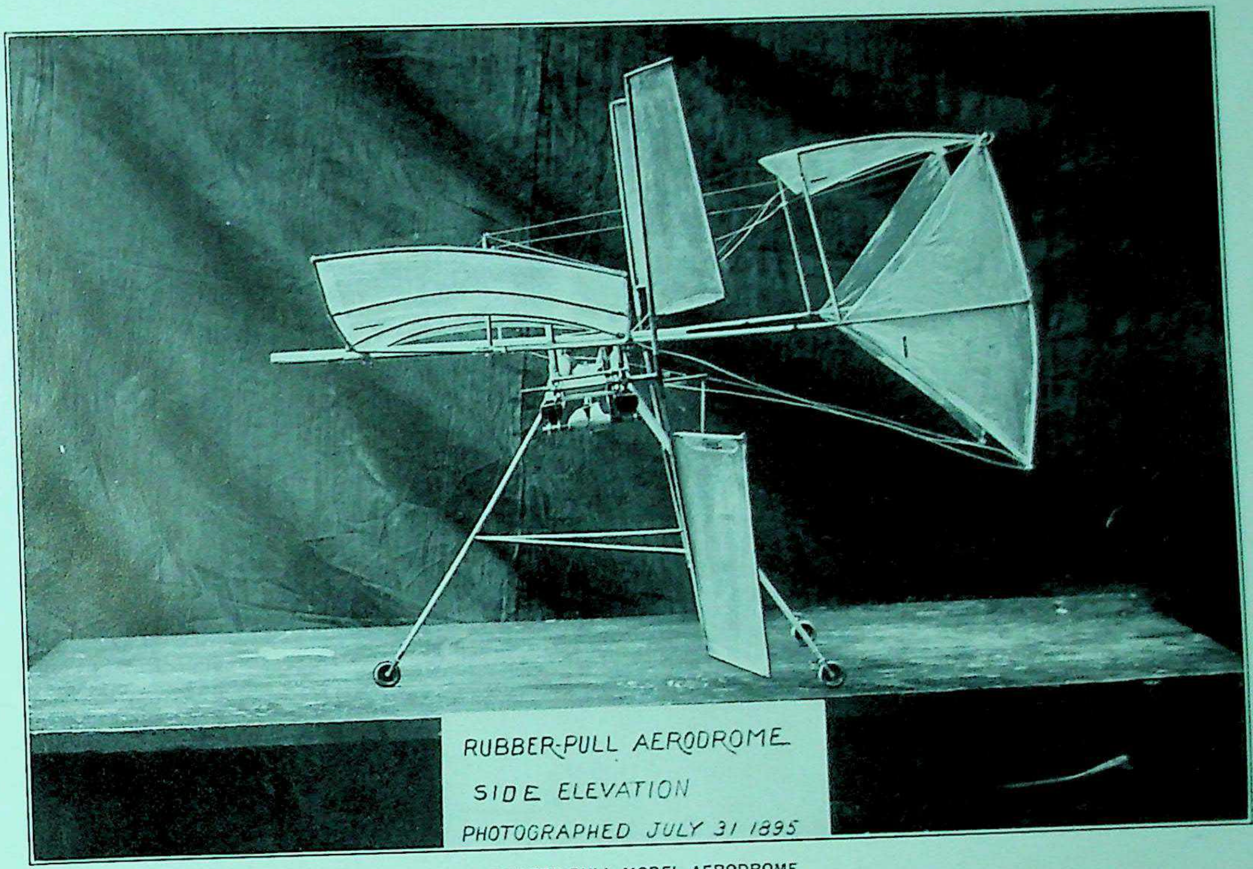
RUBBER-PULL MODEL AERODROME



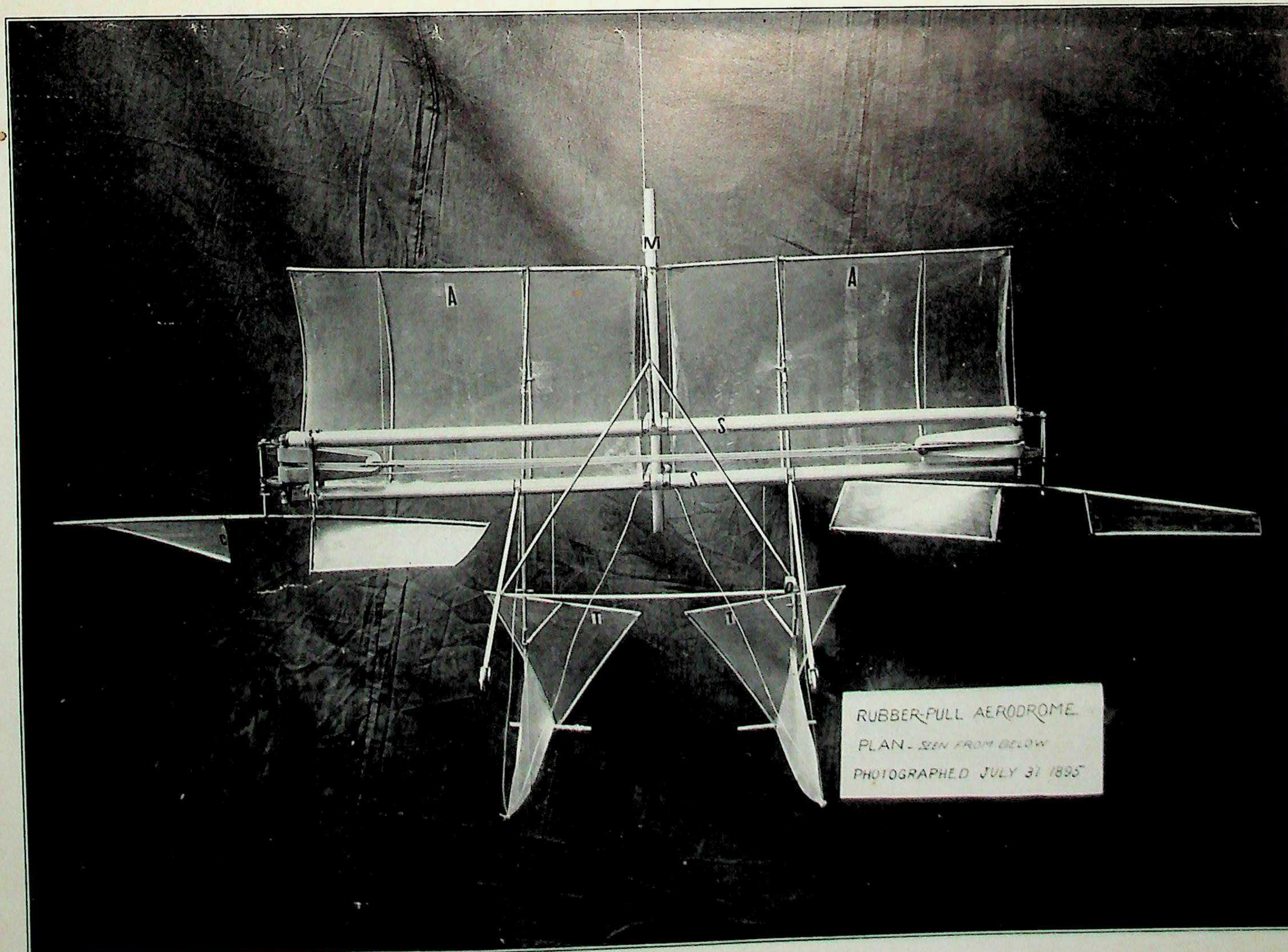
RUBBER-PULL MODEL AERODROME



RUBBER-PULL MODEL AERODROME



RUBBER-PULL MODEL AERODROME



RUBBER-PULL MODEL AERODROME

retical capacity possibly realizable under such conditions, but if we take 1/1000 we shall probably be nearer the mark. Even in this case we have, when using gasoline as fuel, 15,625 foot-pounds per minute, or nearly 0.50 horse-power, as against .0091 horse-power in the case of the rubber, so that even with this waste and with the weight of the engines necessary for a single minute's service, the unit weight of fuel employed in the steam engine gives 55 times the result we get with rubber.

With alcohol we have about $\frac{2}{3}$ the result that is furnished by gasoline, since nearly the same boiler and engine will be used in either case. Certain difficulties which at first appeared to be attendant on the use of gasoline on a small scale induced me to make the initial experiments with alcohol. This was continued because of its convenience during a considerable time, but it was finally displaced in favor of gasoline, not so much on account of the superior theoretical efficiency of the latter, as for certain practical advantages, such as its maintaining its flame while exposed to wind, and like considerations.

Gunpowder

Although there are other explosives possessing a much greater energy in proportion to their weight than gunpowder, this is the only one which could be considered in relation to the present work, and the conclusion was finally reached that it involved so great a weight in the containing apparatus and so much experiment, that, although the simplicity of its action is in its favor where crude means are necessary, experiments with it had better be deferred until other things had been tried.

Hot-Water Engine

A great deal of attention was given to the hot-water engine, but it was never put to practical use in the construction of an aerodrome, partly on account of the necessary weight of a sufficiently strong containing vessel.

Compressed Air

Compressed air, like the other possible sources of power, was investigated, but calculations from well-authenticated data showed that this system of propelling engines would probably be inadequate to sustain even the models in long flights. As the chief difficulty lies in the weight, not of the air, but of the containing vessel, numerous experiments were made in the construction of one at once strong and light. The best result obtained was with a steel tube 40 mm. in diameter, 428 mm. in length, closed at the ends by heads united by wires, which safely contained 538 cubic cm. of air at an initial pressure of 100 atmospheres for a weight of 521 grammes.

If we suppose this to be used, by means of a proper reducing valve, at a mean pressure of 100 pounds, for such an engine as that of Aerodrome No. 5, which takes 60 cubic cm. of air at each stroke, we find that (if we take no account of the loss by expansion) we have 18,329 foot-pounds of energy available, which on the engine described will give 302 revolutions of the propellers.

There are such limits of weight, and the engines must be driven at such high speeds, that the increased economy that might be obtained by re-heating the air would be out of the question. The principal object in using it would have been the avoidance of fire upon the aerodrome, and the expansion of the unheated air would probably have caused trouble with freezing, while the use of hot (i. e. superheated) water was impracticable. So when, after a careful computation, it was found that, having regard to the weight of the containing vessel, only enough compressed air could be stored at 72 atmospheres and used at 4, to run a pair of engines with cylinders 0.9 inch in diameter by 1.6 inches stroke, at a speed of 1200 revolutions per minute for 20 seconds, all further consideration of its adaptation to the immediate purpose was definitely abandoned. This course, however, was not taken until after a model aerodrome for using compressed air had been designed and partially built. Then, after due consideration, it was decided to make the test with carbonic-acid gas instead.

Gas

The gas engine possesses great theoretical advantages. At the time of these experiments, the gas engine most available for the special purposes of the models was one driven by air drawn through gasoline. As the builders could not agree to reduce the weight of a one horse-power engine more than one-half of the then usual model, and as the weight of the standard engine was 470 pounds, it was obvious that to reduce this weight to the limit of less than 3 pounds was impracticable under the existing conditions, and all consideration of the use of gas was abandoned provisionally, although a gasoline engine of elementary simplicity was designed but never built. I purposed, however, to return to this attractive form of power if I were ever able to realize its theoretical advantages on the larger scale which would be desirable.

Electricity

As it was not intended to build the model aerodromes for a long flight, it was thought that the electric motor driven by a primary or storage battery might possibly be utilized. It therefore occurred to me that a battery might be constructed to give great power in proportion to its weight on condition of being short-lived, and that in this form a battery might perhaps advantageously take the place of the dangerous compressed-air tubes that were at the time (1893)

under consideration for driving the models. I assumed that the longest flight of the model would be less than five minutes. Any weight of battery, then, that the model carried in consumable parts lasting beyond this five minutes would be lost, and hence it was proposed to build a battery, the whole active life of which would be comprised in this time, to actuate a motor or motors driving one or two propellers.

According to Daniell, when energy is stored in secondary batteries, over 300,000 megergs per kilogramme of weight can be recovered and utilized if freshly charged.

300,000 megergs = 0.696 horse-power for 1 min.
300,000 megergs = 0.139 horse-power for 5 min.

In a zinc and copper primary battery with sulphuric acid and water, one kilogramme of zinc, oxidized, furnishes at least 1200 calories as against 8000 for one kilogramme of carbon, but it is stated that the zinc energy comes in so much more utilizable a form that the zinc, weight for weight, gives practically, that is in work, 40 per cent that of carbon. The kilogramme of carbon gives about 8000 heat units, each equal to 107 kilogrammetres, or about 6,176,000 foot-pounds. Of this, in light engines, from 5 to 10 per cent, or at least 308,800 foot-pounds, is utilized, and $\frac{2}{5}$ of this, or about 124,000 foot-pounds, would seem to be what the kilogramme of zinc would give in actual work. But to form the battery, we must have a larger weight of fluid than of zinc, and something must be allowed for copper. If we suppose these to bring the weight up to 1 kilogramme, we might still hope to have 50,000 foot-pounds or 1.5 horse-power for one minute, or 0.3 horse-power for 5 minutes.

Storage batteries were offered with a capacity of .25 horse-power for 5 minutes per kilogramme, but according to Daniell one cannot expect to get more than 0.139 horse-power from a freshly charged battery of that weight for the same time.

The plan of constructing a battery of a long roll of extremely thin zinc or magnesium, winding it up with a narrower roll of copper or platinized silver, insulating the two metals and then pouring over enough acid to consume the major portion of the zinc in 5 minutes, was carefully considered, but the difficulties were so discouraging, that the work was not undertaken.

The lightest motors of 1 horse-power capacity of which any trace could be found weighed 25 pounds, and a prominent electrician stated that he would not attempt to construct one of that weight.

In trials with a $\frac{1}{2}$ horse-power motor driving an 80 cm. propeller of 1.00 pitch-ratio, I apparently obtained a development of 0.56 indicated horse-power at 1265 revolutions; but at lower speeds when tried with the Prony brake, the brake horse-power fell to 0.10 at 546 revolutions, and even at 1650 revolutions

it was but 0.262 indicated, with a brake horse-power of 0.144, or 55 per cent of that indicated.

With these results both of theoretical calculation and practical experiment, all thought of propelling the proposed aerodrome by electricity was necessarily abandoned.

Carbonic-Acid Gas

At the first inception of the idea, it seemed that carbonic-acid gas would be the motive power best adapted for short flights. It can be obtained in the liquid form, is compact, gives off the gas at a uniform pressure dependent upon the temperature, and can be used in the ordinary steam engine without any essential modifications. The only provision that it seemed, in advance, necessary to make, was that of some sort of a heater between the reservoir of liquid and the engine, in order to prevent freezing, unless the liquid itself could be heated previous to launching.

The engines in which it was first intended to use carbonic acid were the little oscillating cylinder engines belonging to Aerodrome No. 1. The capacity of each cylinder was 21.2 cu. cm., so that 84.8 cu. cm. of gas would be required to turn the propellers one revolution when admitted for the full stroke, and 101,760 cubic cm. for 1200 revolutions. The density of the liquid at a temperature of 24° C. was taken as .72, and as 1 volume of liquid gives 180 volumes of gas at a pressure of $2\frac{1}{2}$ atmospheres, we have $\frac{101{,}760}{180}=565$ cu. cm. of liquid, or 407 grammes required for 1200 revolutions of the engines.

Thus, a theoretical calculation seemed to indicate that a kilogramme of liquid carbonic acid would be an ample supply for a run of two minutes. The experiments were, at first, somewhat encouraging. The speed and apparent power of the engines were sufficient for the purpose, but the length of time during which power could be obtained was limited.

In 1892, 415 grammes of carbonic acid drove the engines of Aerodrome No. 3 700 revolutions in 60 seconds, 900 in 75, and 1000 in 85 seconds, at the end of which time the gas was entirely expended. The diameter of these cylinders was 2.4 cm., the stroke of the pistons 7 cm., and the work done, that of driving a pair of 50 cm. propellers, when taken in comparison with the propeller tests detailed elsewhere, amounted to an effective horse-power of about 0.10 for the output of the engine.

The difficulties, however, that were experienced were those partially foreseen. The expansion of the gas made such serious inroads upon the latent heat of the liquid, that lumps of solid acid were formed in the reservoir, and could be heard rattling against the sides when the latter was shaken, while the expansion of the exhaust caused such a lowering of temperature at that point, that the

pipes were soon covered with a thick layer of ice, and the free exit of the escaping gas was prevented.

Such difficulties are to be expected with this material, but here they were enhanced by the small scale of the construction and the constant demand for lightness. And it was found to be very hard to fill the small reservoirs intended to carry the supply for the engines. When they were screwed to the large case in which the liquid was received and the whole inverted, the small reservoir would be filled from one-third to one-half full, and nothing that could be done would force any more liquid to enter.

In view of these difficulties, and the objections to using a heater of any sort for the gas, as well as the absolute lack of success attendant upon the experiments of others who were attempting to use liquid CO_2 as a motive power on a large scale elsewhere, experiments were at first temporarily and afterwards permanently abandoned.

The above experiments extended over nearly a year in time, chiefly during 1892, and involved the construction and use of the small aerodromes Nos. 1, 2, and 3, presently described.

CHAPTER IV

EARLY STEAM MOTORS AND OTHER MODELS

In dealing with the development of the aerodrome, subsequent to the early rubber-driven models, the very considerable work done and the failures incurred with other types of motors than steam, have been briefly dealt with in the preceding chapter, but are scarcely mentioned here, as no attempts at long flights were ever successful with any other motor than steam, and no information was gained from any of the experiments made with compressed air, gas, carbonic acid, or electricity, that was of much value in the development of the successful steam machines.

In November, 1891, after the long and unsatisfactory experiments with rubber-driven models already referred to, and before most of the experiments with other available motors than steam had been made, I commenced the construction of the engines and the design of the hull of a steam-driven aerodrome, which was intended to supplement the experiments given in "Aerodynamics" by others made under the conditions of actual flight.

In designing this first aerodrome, here called No. 0, there was no precedent or example, and except for the purely theoretical conditions ascertained by the experiments described in "Aerodynamics," everything was unknown. Next to nothing was known as to the size or form, as to the requisite strength, or as to the way of attaching the sustaining surfaces; almost nothing was known as to the weight permissible, and nothing as to the proper scale on which to build the aerodrome, even if the design had been obtained, while everything which related to the actual construction of boiler and engines working under such unprecedented conditions was yet to be determined by experiment.

The scale of the actual construction was adopted under the belief that it must be large enough to carry certain automatic steering apparatus which I had designed, and which possessed considerable weight. I decided that a flying machine if not large enough to carry a manager, should in the absence of a human directing intelligence, have some sort of automatic substitute for it, and be large enough to have the means of maintaining a long and steady flight, during which the problems (which the rubber-driven models so imperfectly answered) could be effectually solved.

When, in 1891, it was decided to attempt to build this steam aerodrome, the only engine that had been made up to that time with any claim to the lightness and power I was seeking, was the Stringfellow engine, exhibited at the Crystal Palace in London, in 1868, which it was then announced developed 1 horse-

power for a total weight (boiler and engines) of 13 pounds. The original engine came into the possession of the Institution in 1889 as an historical curiosity, but on examination, it was at once evident that it never had developed, and never could develop the power that had been attributed to it, and probably not one-tenth so much.

With the results obtained on the whirling-table at Allegheny as a basis, a theoretical computation of the weight which 1 horse-power would cause to soar showed that, with a plane whose efficiency should be equal to that of a 30×4.8 inch plane set at an angle of 5° and moving at a speed of 34 miles an hour, 1 horse-power would support 120 pounds.[1] With a smaller angle even better results could be obtained, but as the difficulties of guidance increase as the angle diminishes, I did not venture to aim at less than this. In this computation, no allowance was made for the fact that these results were obtained by a mechanism which *forcibly maintained* the supporting surface in the ideal condition of the best attainable angle of attack as if in perfect equilibrium, and above all in the equally ideal condition of perfectly horizontal flight.

Besides this, I had to consider in actual flight the air resistance due to the guy wires and hull, but after making an allowance of as much as three-quarters for these differences between the conditions of experiment and those of free flight, I hoped that 1 horse-power would serve to carry 30 pounds through the air if a supporting surface as large as 3 feet to the pound could be provided, and this was the basis of the construction which I will now describe.

The general form of this Aerodrome No. 0, without wings or propellers, is shown in the accompanying photograph in Plate 10. Its dimensions and its weights, as first designed, and as finally found necessary, are as follows:

COMPARISON OF ESTIMATED AND ACTUAL WEIGHTS OF PARTS OF AERODROME "O"—IN POUNDS AND OUNCES.

	Estimated		Actual	
	lbs.	oz.	lbs.	oz.
Engines	4	0	4	1
Boilers and Burners	8	11	13	14
Pumps and Attachments	0	0	1	10
Steering Apparatus	0	6	0	0
Frame of Hull and Braces, including bowsprit and tail tube	7	7	8	11
Oil tank covering and pipes	0	0	0	13
Shafts, ball bearings (2:1) and wooden propellers (1:7)	1	14	3	8
Wings (5:4) and guys (0:9)	4	0	5	13
Tail	1	5	2	2
Jacket at prow	0	0	4	0
Total without oil or water	27	11	44	8

(The weights attained in the actual making were, as is seen, nearly double those first estimated, and this constant increase of weight under the exigencies of construction was a feature which could never be wholly eliminated.)

[1] See footnote on page 32.

After studying various forms for the hull or body of the prospective aerodrome, I was led to adopt the lines which Nature has used in the mackerel as most advantageous so far as the resistance of the air was concerned, but it proved to be difficult in construction to make the lines of the bow materially different from those of the stern, and in this first model the figure was symmetrical throughout.

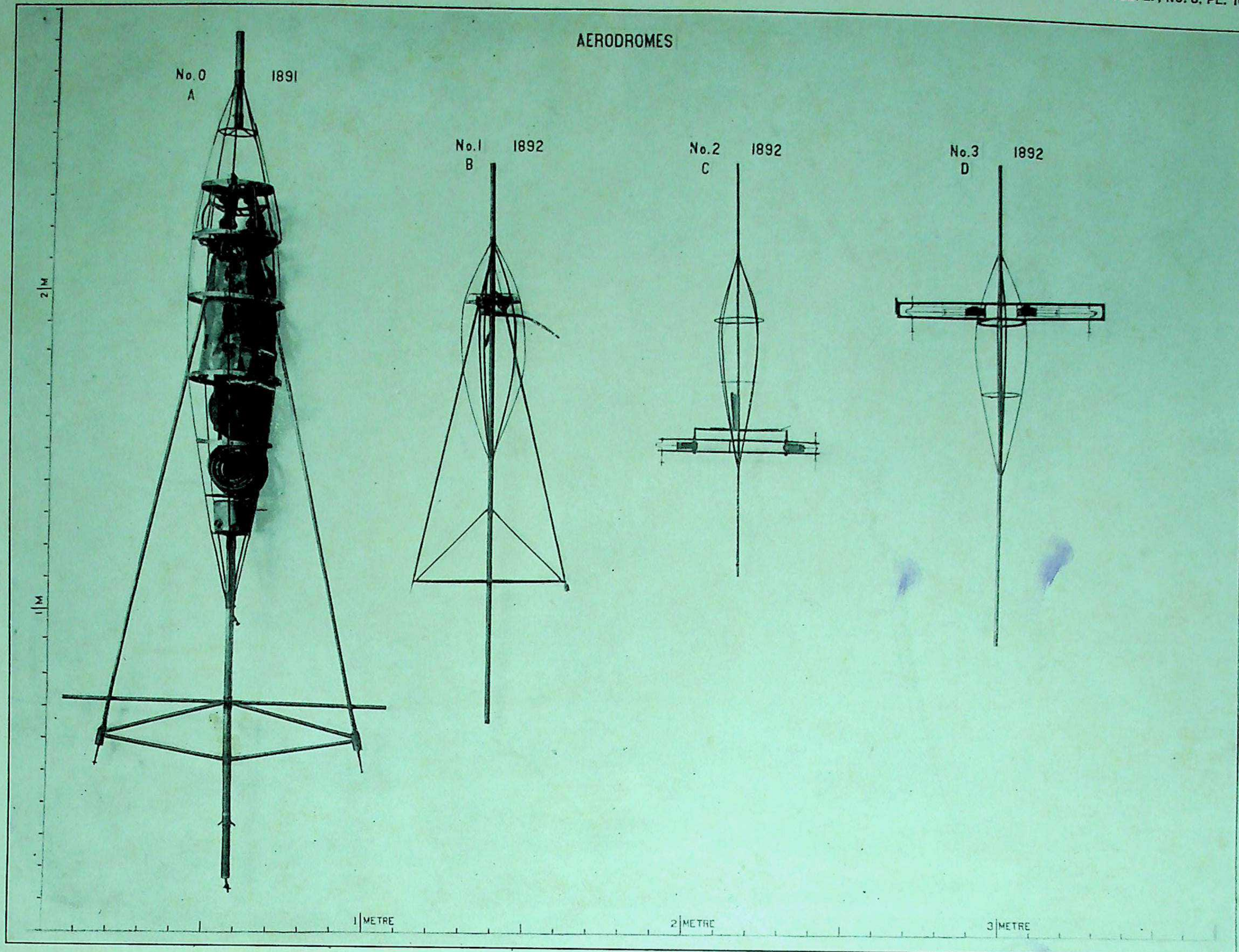
As I wish that my experience may be of benefit to the reader, even in its failures, I will add that I made the not unnatural mistake of building on the plan on which the hull of an ordinary ship is constructed; that is, making the hull support the projecting bowsprit and other parts. In the aerodrome, what corresponds to the bowsprit must project far in advance of the hull to sustain the front wings, and a like piece must project behind it to sustain the rear wings and the tail, or the supporting surfaces of whatever kind. The mistake of the construction lay in disjoining these two and connecting them indirectly by the insufficiently strong hull which supported them. This hull was formed of longitudinal U-shaped ribs of thin steel, which rested on rings made of an alloy of aluminum, which possessed the lightness of the latter metal with very considerable toughness, but which was finally unsatisfactory. I may say parenthetically that in none of the subsequent constructions has the lightness of aluminum been found to compensate for its very many disadvantages. The two rods, which were each 1 metre in length, were with difficulty kept rigorously in line, owing to the yielding of the constructionally weak hull. It would have been better, in fact, to have carried the rod straight through at any inconvenience to the disposition of the boilers and the engine.

I may add that the sustaining surfaces, which were to be nearly flat wings, composed of silk stretched from a steel tube with wooden attachments, were to

[1] The following table taken from "Experiments in Aerodynamics," p. 107, gives the data for soaring of 30 x 4.8 inch planes, weight 500 grammes.

Angle with horizon a.	Soaring speed V.		Work expended per minute.		Weight with planes of like form that 1 horse-power will drive through the air at velocity V.	
	Metres per second.	Feet per second.	Kilogram-metres.	Foot-pounds.	Kilo-grammes.	Pounds.
45°	11.2	36.7	336	2,434	6.8	15
30	10.6	34.8	175	1,268	13.0	29
15	11.2	36.7	86	623	26.5	58
10	12.4	40.7	65	474	34.8	77
5	15.2	49.8	41	297	55.5	122
2	20.0	65.6	24	174	95.0	209

The relations shown in the above table hold true only in case of planes supporting about 1.1 pounds to each square foot of sustaining area. For a different proportion of area to weight, other conditions would obtain.



STEEL FRAMES OF AERODROMES NOS. 0, 1, 2, 3. 1891 AND 1892

them in this respect, regardless of the absolute economy of fuel that might or might not be exhibited. Hence, to the end of my experiments nothing else was used.

Even before the "beehive" boiler was completed, I was anxious to ascertain what could be done with a coil of pipe with a stream of water circulating through it, as well as with various forms of burners, for I realized that the success of the apparatus depended not only upon getting an exceedingly effective heating surface, but also an equally effective flame to do the heating.

For fuel I naturally turned to the liquids as being more compact and readily regulated. Whether to use some of the more volatile hydrocarbons or alcohol, was still an unsolved problem, but my opinion at the time was that, on the limited scale of the model, better results could probably be obtained with alcohol.

In the experiments made with a coil preliminary to the trial of the "beehive" boiler, I tried a simple horizontal coil of $\frac{3}{8}$-inch copper pipe into which two forked burners working on the Bunsen principle and using city illuminating gas, were thrust. The jets were about $\frac{1}{2}$ inch apart. The arrangement primed so badly that the engines could not get rid of the entrained water, and would only make a few turns.

I then tried the same coil with two 1.25-inch drums in the inside and with five longitudinal water tubes at the bottom, beneath which were the same two forked burners used in the previous experiment. The coils were covered with a sheet of asbestos, and two round burners were added. This boiler would hold a steam pressure of about 15 pounds and run the engine slowly; but if the pressure were allowed to rise to 60 pounds, the engine would drive a 2-foot propeller of 18-inch pitch at the rate of about 650 turns per minute for from 80 to 90 seconds, while the steam ran down to 10 pounds, showing that this boiler, at least, was too small. This was further shown in a trial of the plain coil made in October, 1891; 6 pounds of water were evaporated in 32 minutes under a pressure of 60 pounds. This was at the rate of 11.25 pounds per hour, or, taking the U. S. Centennial standard of 30 pounds of evaporation per horse-power, gave an available output of less than $\frac{1}{3}$ horse-power.

With these results before me I decided to make a trial ... m betwe... "
principle upon a smaller scale than in th... horse-power of 0.43 out of the
I used a small boiler of which the in
per tube about 28 gauge thick, and the ... having reduced the capacity of the pumps
This gave 12 feet of $\frac{3}{8}$-inch, and 16 fee... stroke was originally 1.25 inch) I obtained
27 gauge, hard planished copper. ...er by the engine for 41 seconds, with a steam
oz. of water were evaporated in ...re inch, and a rate of revolution of 720 per
per hour. As these coils co... brief period, the shafts sprung and the worm
as the three to be built w...

10 square feet afforded by them could safely be depended upon to provide steam for a 1 horse-power engine. As far as fuel consumption was concerned, the rate of evaporation was about 15.6 pounds of water per pound of gasoline, all of which was satisfactory.

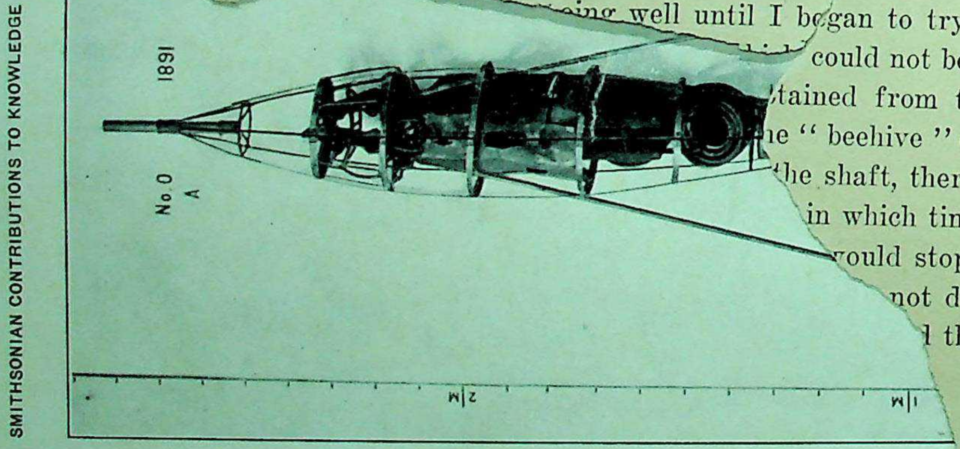
The burner originally designed for use in connection with the "beehive" boilers, consisted of a small tank in which a quantity of gasoline was placed, the space above being filled with compressed air. Rising from the bottom of this tank was a small pipe coiling back and down and ending in an upturned jet from which the gas generated in the coil would issue. The burner thus served to generate its own gas and act as a heater for the boilers at the same time.

In the construction of Aerodrome No. 0, four of the "beehive" coils were placed in a line fore and aft. The fuel tank was located immediately back of the rear coil and consisted of a copper cylinder 11 cm. in diameter and 9 cm. long. The engines were placed immediately in front of the coils, all the apparatus being enclosed in a light framing, as shown in the photograph (Plate 10).

Extending front and back from the hull were the tubes for supporting the wings and tail, each one metre in length. The cross-framing for carrying the propeller shafts was built of tubing 1.5 cm. diameter, and the shafts themselves were of the same size. The ribs of the hull were rings made of angle-irons measuring 1.50×1.75 cm., which were held in place longitudinally by five 0.7 cm. channel bars.

As it had been learned in the preliminary experiments with the model "beehive" boiler that the heated water would not of itself cause a sufficiently rapid circulation to be maintained through the tubes to prevent them from becoming red-hot, two circulating pumps were added for forcing the water through the coils of the two forward and two rear boilers respectively, the water being taken from the lower side of the drum and delivered into the bottom of the coils, which were united at that point for the purpose. A worm was placed upon each of the propeller shafts, just back of the engines, meshing in with a gear on a crank-shaft from which the pumps were driven. This shaft rotated at the rate of 1 to 24, so that for 1200 revolutions of the engine, it would make but 50, driving a sing[illegible] plunger 1.2 cm. in diameter and 2 cm. stroke.

[illegible]ing well until I began to try the apparatus. First,
could not be made to give forth the
tained from the smaller model, and
e "beehive" connected with the com-
he shaft, there were about 250 turns
in which time the steam would fall
ould stop. Then, as we had no
not drive the water through
l that the boilers could be



depended upon to supply the steam that the compound engines would require; but after the whole was completed, the weight, if nothing else, was prohibitory.

I had gone on from one thing to another, adding a little here and a little there, strengthening this part and that, until when the hull was finally completed with the engines and boilers in place, ready for the application of the wings, the weight of the whole was found (allowing 7 pounds for the weight of the wings and tail) to be almost exactly 45 pounds, and nearly 52 pounds with fuel and water. To this excessive weight would have to be added that of the propellers, and as the wings would necessarily have to be made very large in order to carry the machine, and as the difficulties of launching had still to be met, nothing was attempted in the way of field trials, and with great disappointment the decision was made in May, 1892 (wisely, as it subsequently appeared) to proceed no further with this special apparatus.

However, inasmuch as this aerodrome with its engines and boilers had been completed at considerable expense, it was decided to use the apparatus as far as it might be practicable, in order to learn what must be done to secure a greater amount of success in the future. The fundamental trouble was to get *heat*. In the first place there was trouble with the burners, for it seemed to be impossible to get one that would vaporize the gasoline in sufficient quantity to do the work, and various forms were successively tried.

All of the early part of 1892 was passed in trying to get the boilers to work at a steam pressure of 100 pounds per square inch. On account of the defects in the tubes and elsewhere this required much patient labor. The writer, even thus early, devised a plan of using a sort of aeolipile, which should actuate its own blast, but this had to be abandoned on account of the fact that the pear-shaped receivers would not stand the heat. This necessitated a number of experiments in the distillation of gas, in the course of which there was trouble with the pumps, and a continual series of breakages and leakages, so that the middle of April came before I had secured any further satisfaction than to demonstrate that *possibly* the boilers might have a capacity sufficient for the work laid out for them to do; but subsequent experiments showed that even in this I was mistaken, for it was only after additional jets had been put in between the coils that I succeeded in getting an effective horse-power of 0.43 out of the combination.

Finally, on the 14th of April, after having reduced the capacity of the pumps to the dimensions given above (for the stroke was originally 1.25 inch) I obtained the development of 1 full horse-power by the engine for 41 seconds, with a steam pressure of 100 pounds per square inch, and a rate of revolution of 720 per minute. But at the end of this brief period, the shafts sprung and the worm was thrown out of gear.

I pass over numerous other experiments, for their only result was to make it clear that the aerodrome, as it had been constructed, could not be made to work efficiently, even if its great weight had not served as a bar to its flight. It was, therefore, decided to proceed with the construction of another.

That after the failure of the first steam-driven model No. 0, which has just been described, subsequent light models were constructed. These, three in number, made with a view to the employment of carbonic acid or compressed air, but also to the possible use of steam, are shown in Plate 10, Nos. 1, 2, 3; on the same scale as the larger model which had preceded them. In describing these, it will be well to mention constructive features which were experimented on in them, as well as to describe the engines used.

In No. 1, which was intended to be on about $\frac{2}{5}$ the linear scale of No. 0, the constructive fault of the latter, that of making the support depend on a too flexible hull, was avoided, and the straight steel tube ("midrod" it will hereafter be called) was carried through from end to end, though at the cost of inconvenience in the placing of the machinery, in what may be called the hull, which now became simply a protective case built around this midrod. The mistaken device of the long shafts meeting at an angle was, however, retained, and the engines first tried were a pair of very light ones of crude construction.

These were later replaced by a pair of oscillating engines, each 3 cm. diameter by 3 cm. stroke, with a combined capacity of 42 cubic cm. and without cut-off. The midrod was made of light steel tubing 2 cm. outside diameter. The framing for the hull was formed by a single ring of U section, 8 cm. across and 18 cm. in depth, stayed by five ribs of wood measuring 0.7×0.3 cm. The inclined propeller shafts, which were connected by a pair of bevel gears as in No. 0, were made of tubing 0.5 cm. outside diameter, and were intended to turn propellers of from 40 to 45 cm. in diameter. The weight, without engine or reservoir for gas, was 1161 grammes. With a weight equivalent to that of the intended reservoir and engines plus that of the proposed supporting surfaces, the whole weight, independent of fuel or water, was 2.2 kilogrammes.

The engines, which were not strong enough to sustain a pressure of over 2 atmospheres, at an actual pressure of 20 pounds drove the 45 cm. propellers through the long V shafts and lifted only about $\frac{1}{7}$ of the flying weight of the machine. The power developed at the Prony brake was collectively only about .04 horse-power, giving 1200 turns a minute to two 40 cm. propellers. This was the best result obtained.

This aerodrome was completed in June, 1892, but changes in the engines and other attempted improvements kept it under experiment until November of that year, when it appeared to be inexpedient to do anything more with it

Aerodrome No. 2 (see Plate 10), was a still smaller and still lighter construction, in which, however, the midrod was bent (not clearly shown in the photo-

graph), so as to afford more room in the hull. This introduced a constructic weakness which was not compensated by the added convenience, but the pri pal improvement was the abandonment of the inclined propeller shafts, whic was done at the suggestion of Mr. J. E. Watkins, so that the propellers we carried on parallel shafts as in marine practice. These parallel shaf , the driven by two very small engines with cylinders 2.3 cm. in diameter by m. stroke, with a collective capacity of 33 cu. cm. and without cut-off, which ere mounted on a cross-frame attached to the midrod at right angles near the ear end of the hull.

These engines, driven either by steam or by carbonic-acid gas developed 0.035 horse-power at the Prony brake, giving 750 revolutions of the 45 cm. propellers, and lifting about $\frac{1}{5}$ of the total weight which it was necessary to provide for in actual flight. A higher rate of revolution and a better lift were occasionally obtained, but there was little more hope with this than with the preceding models of obtaining power enough to support the actual weight in flight, although such sacrifices had been made for lightness that every portion of the little model had been reduced to what seemed the limit of possible frailty consistent with anything like safety. Thus the midrod was lighter than that of No. 1, being only 1 cm. in outside diameter. The frame was made of thin wooden strips 5 mm. × 3.5 mm., united by light steel rings. The cross framing carrying the engines was also of wood, and was formed of four strips, each 7 mm. × 3 mm. The shafts were but 4 mm. in diameter.

As these engines did not give results that were satisfactory, when using carbonic-acid gas, experiments were commenced to secure a boiler that would furnish the requisite steam. As the "beehive" boiler had proved to be too heavy, and as the steam obtained from it had been inadequate to the requirements, something else had to be devised. A few of the boilers used in 1892 are shown in Fig. 3. The one marked *A* is one of the "beehives," while an element of another form tried is that marked *B*. It consisted of $\frac{3}{8}$-inch copper tubes joined to a drum of 10-oz. copper. This was made in May, 1892, and was tested to a pressure of 50 atmospheres, when it burst without any tearing of the metal.

In July another boiler like that shown at *C* in Fig. 3 was made. This was formed of tubes 3 cm. in diameter, and weighed 348 grammes. It carried about 300 grammes of water and stood a steam pressure of 125 pounds per square inch, but failed to maintain sufficient steam pressure.

Accordingly, in the same month, a third boiler like that shown at *D* was built. It consisted of a tube 12 inches long to which were attached fifteen $\frac{1}{4}$-inch tubes each 7 inches long, in the manner shown. The heating surface of this boiler, including the tubes and the lower half of the drum, amounted to 750 square cm., and it was thought that this would be sufficient to supply steam for a flight of a

[illegible]ite[illegible]d a half. But when a test was made, it also was found to be deficient i[illegible] [illegible]ear[illegible]g power even after changes were made in it which occupied much time.

By [illegible] first of October, 1892, there had been built one large aerodrome that [illegible]uld n[illegible] pos[illegible]ibly fly, a smaller one, No. 1, on $\frac{3}{5}$ the linear scale of No. 0, with [illegible] pair [illegible] engines but no means of driving them, and the still smaller No. 2 with a boiler that [illegible]as yet untried.

Aerodrome No. 3 (Plate 10) was an attempt to obtain better conditions than [illegible]ad existed in the preceding model without any radical change except that of moving the cross frame, which carried the engines and propellers, nearer the front of the machine. Instead of the oscillatory engines used up to this time, two stationary cylinder engines, each 2.4 cm. in diameter and 4 cm. stroke, having a combined capacity of 36 cu. cm. without cut-off were employed for driving the propellers. The engines, though occasionally run in trials with steam from a stationary boiler, were intended to be actuated either by compressed air or carbonic-acid gas contained in a reservoir which was not actually constructed, but whose weight was provisionally estimated at 1 kilogramme. The weight of the aerodrome without this reservoir was but 1050 grammes, including the estimated weight of the sustaining surfaces, which consisted principally of two wings, each about 1 metre in length by 30 cm. in breadth and which were in fact so slight in their construction, that it is now certain that they could not have retained their shape in actual flight.

The only trials made with this aerodrome, then, were in the shop, of which it is sufficient to cite those of November 22, 1892, when under a pressure of 30 pounds, the maximum which the engines would bear, two 50 cm. propellers were driven at 900 revolutions per minute, with an estimated horse-power of 0.07, about 35 per cent of the weight of the whole machine being lifted. This was a much more encouraging result than any which had preceded, and indicated that it was possible to make an actual flight with the aerodrome if the boilers could be ignored, the best result having been obtained only with carbonic acid supplied without limit from a neighboring ample reservoir.

This aerodrome was also tested while mounted upon a whirling-arm and allowed to operate during its advance through the air. The conclusion reached with it at the close of 1892, after a large part of the year passed in experiments with carbonic-acid gas and compressed air, was that it was necessary to revert to steam, and that whatever difficulties lay in the way, some means must be found of getting sufficient power without the weight which had proved prohibitory in No. 0.

With this chapter, then, and with the end of the year 1892, I close this very brief account of between one and two years of fruitless experiment in the construction of models supplied with various motors, subsequent to and on a larger scale indeed than the toy-like ones of india rubber, but not even so efficient as those had been, since they had never procured a single actual flight.

CHAPTER V

ON SUSTAINING SURFACES

The following general considerations may conveniently precede the particular description of the balancing of the aerodrome.

In " Experiments in Aerodynamics," I have given the result of trials, showing that the pressure (or total resistance) of a wind on a surface 1 foot square, moving normally at the velocity of 1 foot per second, is 0.00166 pounds, and that this pressure increases directly as the surface of the plane, and (within our experimental condition) as the square of the velocity,[1] results in general accordance with those of earlier observers.

I have further shown by independent investigations that while the shape of the plane is of secondary importance if its movement be normal, the shape and " aspect " greatly affect the resultant pressure when the plane is inclined at a small angle, and propelled by such a force that its flight is horizontal, that is, under the actual conditions of soaring flight.

I have given on page 60 of " Aerodynamics," the primary equations,

$$P_a = P_{90} F(\alpha) = kAV^2F(\alpha),$$
$$W = P_a \cos \alpha = kAV^2F(\alpha) \cos \alpha,$$
$$R = P_a \sin \alpha = kAV^2F(\alpha) \sin \alpha,$$

where W is the weight of the plane under examination (sometimes called the "lift"); R the horizontal component of pressure (sometimes called the "drift"); k is the constant already given; A the area in square feet; V the velocity in feet per second; F a function of α (to be determined by experiment); α the angle which, under these conditions, gives horizontal flight.

I have also given on page 66 of the same work the following table showing the actual values obtained by experiment on a plane, 30×4.8 inches (=1 sq. ft.), weighing 500 grammes (1.1 pounds):

Angle with horizon α.	Soaring speed V.		Horizontal pressure R.	Work expended per minute 60 RV.		Weight with planes of like form that 1 horse-power will drive through the air at velocity V.	
	Metres per second.	Feet per second.	Grammes.	Kilogram-metres.	Foot-pounds.	Kilo-grammes.	Pounds.
45°	11.2	36.7	500	336	2,434	6.8	15
30	10.6	34.8	275	175	1,268	13.0	29
15	11.2	36.7	128	86	623	26.5	58
10	12.4	40.7	88	65	474	34.8	77
5	15.2	49.8	45	41	297	55.5	122
2	20.0	65.6	20	24	174	95.0	209

[1] This pressure per unit of area varies with the area itself, but in a degree which is negligible for our immediate purpose.

It cannot be too clearly kept in mind that these values refer to *horizontal* flight, and that for this the weight, the work, the area, the angle and the velocity are inseparably connected by the formulæ already given.

It is to be constantly remembered also, that they apply to results obtained under almost perfect theoretical conditions as regards not only the maintenance of equilibrium and horizontality, but also the rigid maintenance of the angle α and the comparative absence of friction, and that these conditions are especially "theoretical" in their exclusion of the internal work of the wind observable in experiments made in the open wind.

Experiments in the Open Wind

I have pointed out [2] that an indefinite source of power for the maintenance of mechanical flight, lies in what I have called the "internal work" of the wind. It is easy to see that the actual effect of the free wind, which is filled with almost infinitely numerous and incessant changes of velocity and direction, must differ widely from that of a uniform wind such as mathematicians and physicists have almost invariably contemplated in their discussions.

Now the artificial wind produced by the whirling-table differs from the real wind not only in being caused by the advancing object, whose direction is not strictly linear, and in other comparatively negligible particulars, but especially in this, that in spite of little artificial currents the movement on the whole is regular and uniform to a degree strikingly in contrast with that of the open wind in nature.

In a note to the French edition of my work, I have called the attention of the reader to the fact that the figures given in the Smithsonian publication can show only a small part of the virtual work of the wind, while the plane, which is used for simplicity of exposition, is not the most advantageous form for flight; so that, as I go on to state, the realization of the actually successful aerodrome must take account of the more complex conditions actually existing in nature, which were only alluded to in the memoir, whose object was to bring to attention the little considered importance of the then almost unobserved and unstudied minute fluctuations which constitute the internal work of the wind. I added that I might later publish some experimental investigations on the superior efficiency of the real wind over that artificially created. The experiments which were thus alluded to in 1893, were sufficient to indicate the importance of the subject, but the data have not been preserved.

What immediately follows refers, it will be observed, more particularly to the work of the whirling-table.

[2] See "Internal Work of the Wind"; also Revue de L'Aeronautique, 3e Livraison, 1893.

Relation of Area to Weight and Power

In order to get a more precise idea of the character of the alteration introduced into these theoretical conditions by the variation of any of them, let us, still confining ourselves to the use of the whirling-table, suppose that the plane in question while possessing the same weight, shape, and angle of inclination, were to have its area increased, and to fix our ideas, we will suppose that it became 4 square feet instead of 1 as before. Then, from what has already been said, V, the velocity, must vary inversely as the square root of the area; that is, it must, under the given condition, become one-half of what it had been, for if V did not alter, the impelling force continuing the same, the plane would rise and its flight no longer be horizontal, unless the weight, now supposed to be constant, were itself increased so as to restore horizontality.

I have repeated Table XIII under the condition that the area be quadrupled, while all the other conditions remain constant, except the soaring speed, which must vary.

α	Soaring speed (feet per second) V'.	Work. Work expended per minute. $A = 4$ sq. ft. $W = 500$ gr. $= 1.1$ lbs.	Weight. Weight of like planes which 1 H.P. will drive through the air with velocity V'.
		Foot-pounds.	*Pounds.*
45°	18.4	1,217	30
30	17.4	634	57
15	18.4	312	116
10	20.4	237	154
5	24.9	148	244
2	32.8	87	418

W is the weight of the single plane; A is the area; R is the horizontal "drift." Wt is the weight of like planes which 1 H. P. will drive at velocity V. Work is RV.

I. If Work is constant, R varies as $\sqrt[3]{A}$. II. If R is constant, Work varies as $\frac{1}{\sqrt[3]{A}}$. III. If W is constant while A varies, the weight which 1 H. P. will support varies as $\sqrt{A}$.

The reader is reminded that these are simply deductions from the equations given in "Aerodynamics," and that these deductions have not been verified by direct trial, such as would show that no new conditions have in fact been introduced in this new application. While, however, these deductions cannot convey any confidence beyond what is warranted by the original experiments, in their general trustworthiness as working formulæ at this stage of the investigations, we may, I think, feel confidence.

I may, in view of its importance, repeat my remark that the relation of area and weight which obtain in practice, will depend upon yet other than these theoretical considerations, for, as the flight of the free aerodrome cannot be expected to be exactly horizontal nor maintained at any constant small angle, the

data of "Aerodynamics" (obtained in constrained horizontal flight with the whirling-table) are here insufficient. They are insufficient also because these values are obtained with small rigid planes, while the surfaces we are now to use cannot be made rigid under the necessary requirements of weight, without the use of guy wires and other adjuncts which introduce head resistance.

Against all these unfavorable conditions we have the favoring one that, other things being equal, somewhat more efficiency can be obtained with suitable curved surfaces than with planes.[3]

I have made numerous experiments with curves of various forms upon the whirling-table, and constructed many such supporting surfaces, some of which have been tested in actual flight. It might be expected that fuller results from these experiments should be given than those now presented here, but I am not yet prepared to offer any more detailed evidence at present for the performance of curved surfaces than will be found in Part III.[4] I do not question that curves are in some degree more efficient, but the extreme increase of efficiency in curves over planes understood to be asserted by Lilienthal and by Wellner, appears to have been associated either with some imperfect enunciation of conditions which gave little more than an apparent advantage, or with conditions nearly impossible for us to obtain in actual flight.

All these circumstances considered, we may anticipate that the power required (or the proportion of supporting area to weight) will be very much greater in actual than in theoretical (that is, in constrained horizontal) flight, and the early experiments with rubber-driven models were in fact successful only when there were from three to four feet of sustaining surface to a pound of weight. When such a relatively large area is sought in a large aerodrome, the construction of light, yet rigid, supporting surfaces becomes a nearly insuperable difficulty, and this must be remembered as consequently affecting the question of the construction of boiler, engines and hulls, whose weight cannot be increased without increasing the wing area.

[3] More recent experiments conducted under my direction by Mr. Huffaker give similar results, but confirm my earlier and cruder observations that the curve, used alone, for small angles, is much more unstable than the plane.

[4] As stated in the Preface, Part III has not yet been prepared for publication.

CHAPTER VI

BALANCING THE AERODROME

By " balancing " I mean such an adjustment of the mean center of pressure of the supporting surfaces with reference to the center of gravity and to the line of thrust, that for a given speed the aerodrome will be in equilibrium, and will maintain steady horizontal flight. " Balance " and " equilibrium " as here used are nearly convertible terms.

Lateral Stability

Equilibrium may be considered with reference to lateral or longitudinal stability. The lateral part is approximately secured with comparative ease, by imitating Nature's plan, and setting the wings at a diedral angle, which I have usually made 150°. Stability in this sense cannot be secured in what at first seems an obvious way—by putting a considerable weight in the central plane and far below the center of gravity of the aerodrome proper, for this introduces rolling. Thence ensues the necessity of carrying the center of gravity more nearly up to the center of pressure than would otherwise be necessary, and so far introducing conditions which tend to instability, but which seem to be imposed upon us by the circumstances of actual flight. With these brief considerations concerning lateral stability, I pass on to the far more difficult subject of longitudinal stability.

Longitudinal Stability

My most primitive observation with small gliding models was of the fact that greater stability was obtained with two pairs of wings, one behind the other, than with one pair (greater, that is, in the absence of any instinctive power of adjustment).

This is connected with the fact that the upward pressure of the air upon both pairs may be resolved into a single point which I will call the " center of pressure," and which, in stable flight, should (apart from the disturbance by the propeller thrust) be over the center of gravity. The center of pressure in an advancing inclined plane in soaring flight is, as I have shown in " Aerodynamics," and as is otherwise well known, always in advance of the center of figure, and moves forward as the angle of inclination of the sustaining surfaces diminishes, and, to a less extent, as horizontal flight increases in velocity. These facts furnish the elementary ideas necessary in discussing this problem of equilibrium, whose solution is of the most vital importance to successful flight.

The solution would be comparatively simple if the position of the *CP* could be accurately known beforehand, but how difficult the solution is may be realized from a consideration of one of the facts just stated, namely, that the position of the center of pressure in horizontal flight shifts with the velocity of the flight itself, much as though in marine navigation the trim of a steamboat's hull were to be completely altered at every change of speed. It may be remarked here that the center of pressure, from the symmetry of the aerodrome, necessarily lies in the vertical medial plane, but it may be considered with reference to its position either in the plane XY (cp_1) or in the plane YZ (cp_2). The latter center of pressure, as referred to in the plane YZ, is here approximately calculated on the assumption that it lies in the intersection of this vertical plane by a horizontal one passing through the wings half way from root to tip.

Experiments made in Washington, later than those given in "Aerodynamics," show that the center of pressure, (cp_1) on a plane at slight angles of inclination, may be at least as far forward as one-sixth the width from the front edge. From these later experiments it appears probable also that the center of pressure moves forward for an increased speed even when there has been no perceptible diminution of the angle of the plane with the horizon, but these considerations are of little value as applied to curved wings such as are here used. Some observations of a very general nature may, however, be made with regard to the position of the wings and tail.

In the case where there are two pairs of wings, one following the other, the rear pair is less efficient in an indefinite degree than the front, but the action of the wings is greatly modified by their position with reference to the propellers, and from so many other causes, that, as a result of a great deal of experiment, it seems almost impossible at this time to lay down any absolute rule with regard to the center of pressure of any pair of curved wings used in practice.

Later experiments conducted under my direction by Mr. E. C. Huffaker, some of which will appear in Part III, indicate that upon the curved surfaces I employed, the center of pressure moves forward with an increase in the (small) angle of elevation, and backward with a decrease, so that it may lie even behind the center of the surface. Since for some surfaces the center of pressure moves backward, and for others forward, it would seem that there might be some other surface for which it will be fixed. Such a surface in fact appears to exist in the wing of the soaring bird. These experiments have been chiefly with rigid surfaces, and though some have been made with elastic rear surfaces, these have not been carried far enough to give positive results.

The curved wings used on the aerodromes in late years have a rise of one in twelve, or in some cases of one in eighteen,[1] and for these latter the following empirical local rule has been adopted:

[1] See footnote page 47.

The center of pressure on each wing with a horizontal motion of 2000 feet per minute, is two-fifths of the distance from front to rear. Where there are two pair of wings of equal size, one following the other, and placed at such a distance apart and with such a relation to the propellers as here used, the following wing is assumed to have two-thirds of the efficiency of the leader per unit of surface. If it is half the size of the leader, the efficiency is assumed to be one-half per unit of surface. If it is half as large again as the leader, its efficiency is assumed to be eight-tenths per unit of surface. For intermediate sizes of following wing, intermediate values of the efficiency may be assumed.

These rules are purely empirical and only approximate. As approximations, they are useful in giving a preliminary balance, but the exact position of the center of pressure is rarely determinable in either the horizontal or vertical plane, except by experiment in actual flight. The position of the center of gravity is found with all needed precision by suspending the aerodrome by a plumb-line in two positions, and noting the point of intersection of the traces of the line, and this method is so superior to that by calculation, that it will probably continue in use even for much larger constructions than the present.

The principal factor in the adjustment is the position of the wings with reference to the center of gravity, but the aerodrome is moved forward by the thrust of its propellers, and we must next recall the fact of experiment that as it is for constructional reasons difficult to bring the thrust line in the plane of the center of pressure of the wings, it is in practice sufficiently below them to tend to tip the front of the aerodrome upward, so that it may be that equilibrium will be attained only when CP_1 is *not* over CG_1.

In the discussion of the equilibrium, then, we must consider also the effect of thrust, and usually assume that this thrust-line is at some appreciable distance below the center of pressure.

We may conveniently consider two cases:

1. That the center of pressure is not directly over the center of gravity; that is, $CG_1 - CP_1 = a$, and estimate what the value of a should be in order that, during horizontal flight, the aerodrome itself shall be horizontal; or,

---

[1] According to Wellner ("Zeitschrift für Luftschiffahrt," Beilage, 1893), in a curved surface with 1/12 rise, if the angle of inclination of the chord of the surface be α, and the angle between the direction of resultant air pressure and the normal to the direction of motion be β, then $\beta < \alpha$ and the soaring speed is

$$V = \sqrt{\frac{P}{K} \times \frac{1}{F(\alpha) \times \cos\beta}}$$

while the efficiency is

$$\frac{W}{R} = \frac{\text{Weight}}{\text{Resistance}} = \tan\beta$$

The following values were derived from experiments in the wind:

$\alpha =$	$-3°$	$0°$	$+3°$	$6°$	$9°$	$12°$
$F(\alpha) =$	0.20	0.80	0.75	0.90	1.00	1.05
Tan $\beta =$	0.01	0.02	0.03	0.04	0.10	0.17

so that according to him, a curved surface shows finite soaring speeds when the angle of inclination is 0° or even slightly negative.

2. Consider that the center of pressure is directly over the center of gravity ($CP_1 - CG_1 = 0$), and in this case inquire what angle the aerodrome itself may take during horizontal flight.

First case. The diagram (Fig. 4) represents the resultants of the separate system of forces acting on the aerodrome, and these resultants will lie in a vertical medial plane from the symmetry of their disposition.

Let *af* represent the resultant of the vertical components of the pressure on the wings; the horizontal component will lie in the line *ae*.

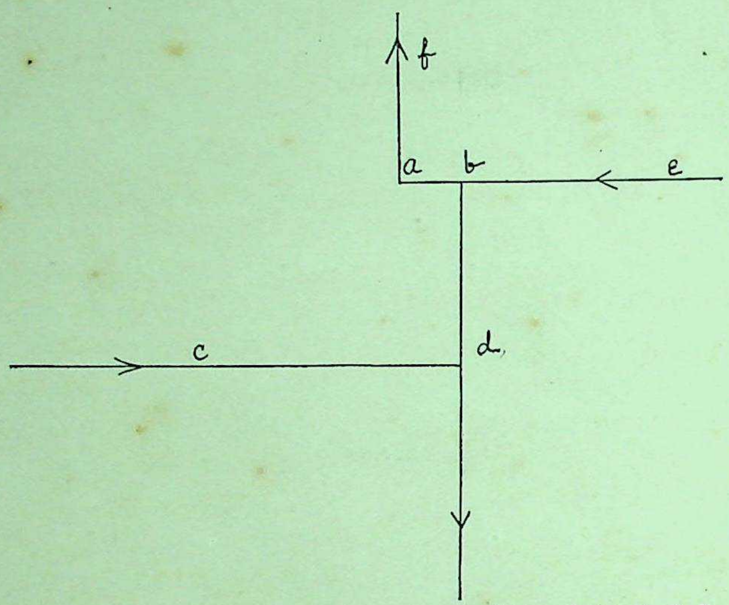


FIG. 4. Diagram showing relation under certain conditions of thrust, C. P. and C. G.

Let the center of gravity be in the line *bd*, and the resultant thrust of the propellers be represented by *cd*.

Let W=weight of aerodrome.

Let T=thrust of propellers.

Then if we neglect the horizontal hull resistance, which is small in comparison with the weight, equilibrium obtains when $W \times ab = T \times bd$.

Second case. The diagram (Fig. 5) represents the same system of forces as Fig. 4, but in this case the point of support is directly over the center of gravity g, when the axis of the aerodrome is horizontal.

Let W=weight of aerodrome.

Let T=thrust of the propellers.

Let R=distance of CG_2 below $CP_2 = ag$.

Let S=distance of thrust-line below $CP_2 = ad$.

If now the aerodrome under the action of the propellers be supposed to turn about the CP_2 (or, a) through an angle α, so that g takes the position g', we

obtain by the decomposition of the force of gravity an element $g'k = W \sin \alpha$ which acts in a direction parallel to the thrust-line.

If we again neglect the horizontal hull resistance, equilibrium will be obtained when

$$kg' \times ag' = T \times ad'$$

or

$$WR \sin \alpha = TS$$

$$\therefore \alpha = \sin^{-1} \frac{TS}{WR}.$$

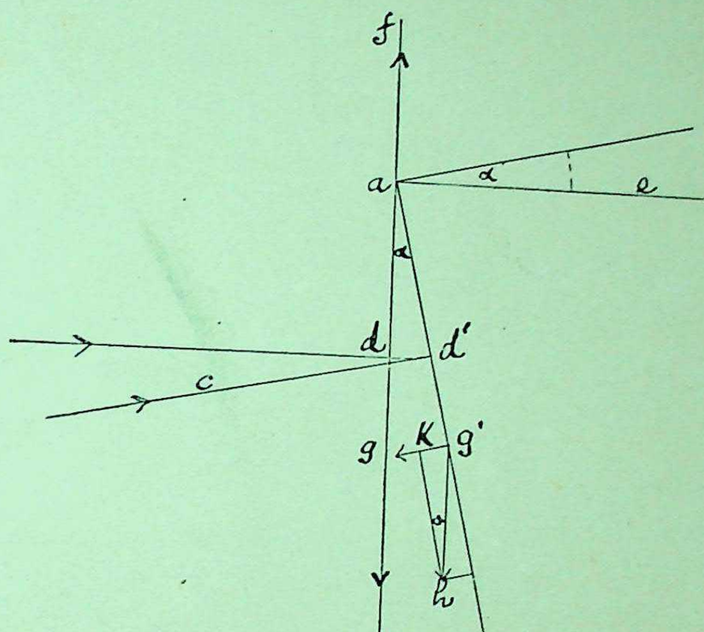


FIG. 5. Diagram showing relation under certain conditions of thrust, C. P. and C. G.

The practical application of these rules is greatly limited by the uncertainty that attaches to the actual position of the center of pressure, and this fact and also the numerical values involved may be illustrated by examples.

CONDITION OF AERODROME NO. 6, NOVEMBER 28, 1896

The weight was 12.5 kilos. On November 28, the steam pressure was less than 100 pounds, and the thrust may be taken at 4.5 kilos. The distance *bd* was 25 cm.

Hence $$12.5 \times ab = 4.5 \times 25 \text{ cm.}$$

$$ab = 9 \text{ cm.}$$

This appears to give the position of CP_1, but CP_1 is a resultant of the pressure on both wings, and its position is determined by the empirical rule just cited. We

cannot tell in fact, then, with exactness how to adjust the wings so that $CG_1 - CP_1$ may be 9 cm., and equilibrium was in fact obtained in flight when (the empirically determined) $CG_1 - CP_1 = 3$ cm.

Again, let it be supposed that CP_1 was really over CG_1.... The distance of the center of gravity below the center of pressure is 43 cm. $= R$.

Then $$\alpha = \sin^{-1} \frac{4.5 \times 25}{12.5 \times 43} = 12^\circ \text{ nearly.}$$

The doubt as to the actual position of the resultant center of pressure, then, renders the application of the rule uncertain. In practice, we are compelled (unfortunately) after first calculating the balance, by such rules as the above, and after it has been thus found with approximate correctness, to try a preliminary flight. Having witnessed the actual conditions of flight, we must then readjust the position of the wings with reference to the center of gravity, arbitrarily, within the range which is necessary. This readjustment should be small.

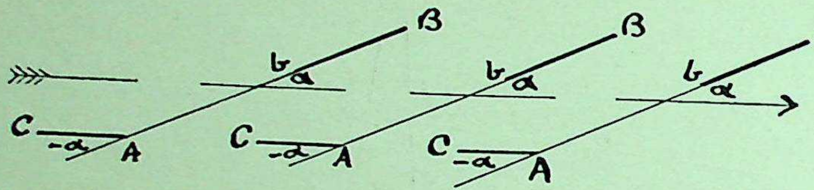


FIG. 6. Diagram showing effect of Penaud tail.

In the preceding discussion it has been assumed that, if there is a flat tail or horizontal rudder, it supports no portion of the weight. This is not an indispensable condition but it is very convenient, and we shall assume it. In this case the action of the so-called Pénaud rudder becomes easily intelligible. This is a device, already referred to in Chapter II, made by Alphonse Pénaud for the automatic regulation of horizontal flight, and it is as beautiful as it is simple.

Let AB (Fig. 6) be a schematic representation of an aerodrome whose supporting surface is Bb, and let it be inclined to the horizon at such an angle α that its course at a given speed may be horizontal. So far it does not appear that, if the aerodrome be disturbed from this horizontal course, there is any self-regulating power which could restore it to its original course; but now let there be added a flat tail AC set at an angle $-\alpha$ with the wing. This tail serves simply for direction, and not for the support of the aerodrome, which, as already stated, is balanced so that the CG comes under the CP of the wing Bb.

It will be seen on a simple inspection that the tail under the given conditions is horizontal, and that, presenting its edge to the wind of advance, it offers no resistance to it, so that if the front rises and the angle α increases, the wind will strike on the under side of the tail and thereby tend to raise the rear and depress

the front again. If the angle α diminish, so that the front drops, the wind will strike the upper surface of the tail, and equally restore the angle α to the amount which is requisite to give horizontal flight. If the angle α is not chosen originally with reference to the speed so as to give horizontal flight, the device will still tend to continue the flight in the straight line which the conditions impose, whether that be horizontal or not.

From this description of its action, it will be seen that the Pénaud tail has the disadvantage of giving an undulatory flight, if the tail is made rigid. This objection, however, can be easily overcome by giving to it a certain amount of elasticity. It does not appear that Pénaud gave much attention to this feature, but stress is laid upon it in the article "Flight," in the ninth edition of the Encyclopædia Britannica, and I have introduced a simple device for securing it.

The complete success of the device implies a strictly uniform velocity and other conditions which cannot well be fulfilled in practice. Nevertheless, it is as efficient a contrivance for its object as has yet been obtained.

More elaborate devices have been proposed, and a number of them, depending for their efficiency upon the action of a variety of forces, have been constructed by the writer, one of which will be described later. This has the advantage that it tends to secure absolutely horizontal flight, but it is much inferior in simplicity to the Pénaud tail.

Apart from considerations about the thrust, the *CP* is in practice always almost directly over the *CG,* and this relationship is, according to what has been suggested, obtained by moving the supporting surfaces relatively to the *CG,* or *vice versa,* remembering, however, that, as these surfaces have weight, any movement of them alters the *CG* of the whole, so that successive readjustments may be needed. The adjustment is further complicated by another important consideration, namely, that those parts which *change* their weight during flight (like the water and the fuel) must be kept very near the *CG.* As the water and fuel tanks are fixed, it appears, then, that the center of gravity of the whole is practically fixed also, and this consideration makes the adjustment a much more difficult problem than it would be otherwise.[2]

[2] The following formulæ proposed by Mr. Chas. M. Manly show how the center of pressure may be moved any desired distance either forward or backward without in any way affecting the center of gravity, and by merely moving the front and rear wings the same amounts but in opposite directions, the total movement of each wing being in either case five times the amount that it is desired to move the mean CP_1, and the direction of movement of the front wing determining the direction of movement of CP_1.

In Figure 7, CP_{fw} and CP_{rw} are the centers of pressure of the front and rear wings respectively; the weights of the wings, which are assumed to be equal and concentrated at their centers of figure, are represented by w, w, and a is the distance of the center of pressure in either wing from its center of figure. The original mean center of pressure of the aerodrome is CP_1. W is the weight of the aerodrome, supposed to be concentrated at CG_1, while m is the distance from CP_{rw} to CG_1.

Now, if we have assumed that the rear wing, being of the same size as the front one, has a lifting effect of only 0.66, and on this assumption have calculated the proper relative positions of the front and rear wings to cause the CP_1 to come directly over the CG_1, and upon testing the aerodrome find

that it is too heavy in front and, therefore, wish to move the center of pressure forward an amount, say b, without affecting the center of gravity, we can calculate the proper relative positions of the front and rear wings in the following manner. While the aerodrome as a whole is balanced at the point CG_1, the weight of the wings is not balanced around this point, for the rear wing, owing to its decreased lifting effect, is proportionately farther from CP_1 than the front wing. In order, therefore, to avoid moving the center of gravity of the machine as a whole, any movement of the wings must be made in such a way as to cause the difference between the weight of the rear wing multiplied by its distance from CG_1 and the weight of the front wing multiplied by its distance from CG_1 to equal a constant: that is,

$$w(m+a) - w(0.66m - a) = \text{constant},$$

and

$$0.33wm + 2wa = \text{constant}.$$

If now the wings be moved so that CP_1 is moved forward a distance b, we may indicate the distance from CG_1 to the new CP_{rw} by z, and equating the difference between the weight of the rear wing

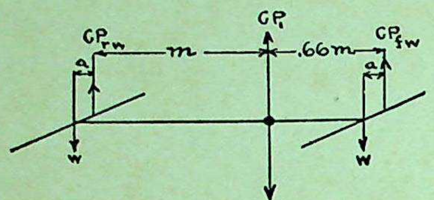


FIG. 7.

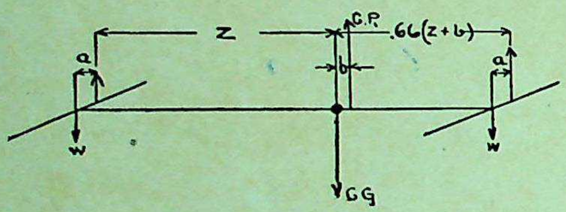


FIG. 8.

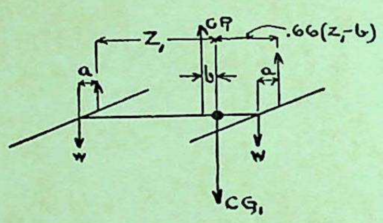


FIG. 9.

FIGS. 7-9. Diagrams illustrating formulæ for moving C. P. without disturbing C. G.

multiplied by its new distance from CG_1 and the weight of the front wing multiplied by its new distance from CG_1, and making this difference equal to the constant difference, we can calculate z in terms of m and b, as follows:

Fig. 8,

$$w(a+z) - w(0.66(z+b) + b - a) = 0.33wm + 2wa,$$

$$\therefore z = m + 5b.$$

Knowing z, we readily find that the new distance from CP_{fw} to CG_1 equals:

$$0.66(z+b) + b = 0.66m + 5b.$$

In a similar manner we may calculate the proper relative positions of the front and rear wings when we wish to move the center of pressure backward a distance, b, from the original CP_1 without changing the position of CG_1. From Fig. 7, we have as before:

$$w(m+a) - w(0.66m - a) = \text{constant},$$
$$0.33wm + 2wa = \text{constant}.$$

Fig. 9,

$$w(z_1 + a) - w(0.66(z_1 - b) - b - a) = 0.33wm + 2wa.$$

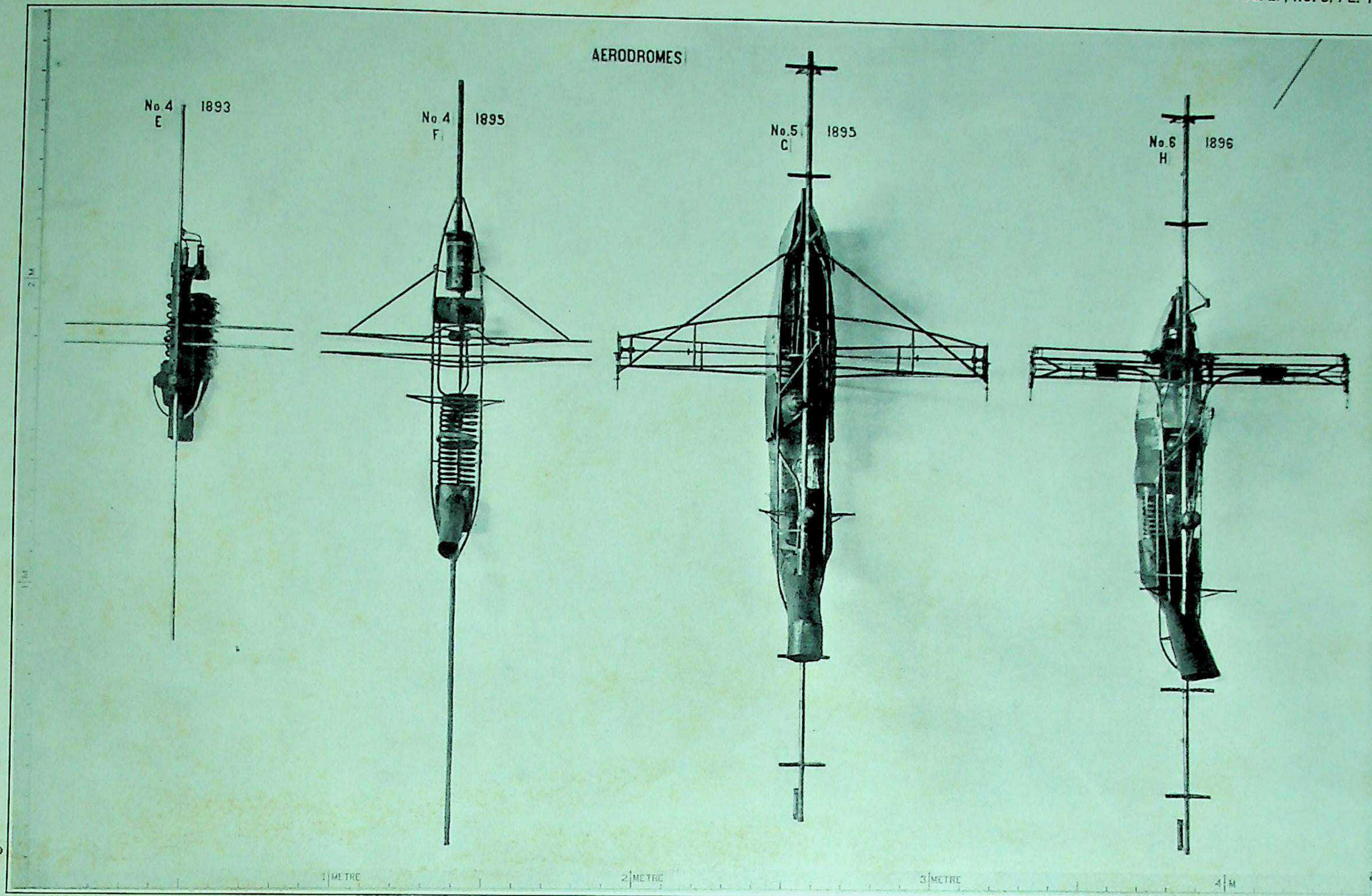
$$\therefore z_1 = m - 5b.$$

Similarly we have for the new distance from CP_{fw} to CG_1:

$$0.66(z_1 - b) - b = 0.66m - 5b.$$

This Ban.

This Book belong to Br. Avinash
Chandra Kushavaha



STEEL FRAMES OF AERODROMES NOS. 4, 5, 6. 1893, 1895 AND 1896

CHAPTER VII

HISTORY OF CONSTRUCTION OF FRAME AND ENGINES OF AERODROMES

During the years 1892 and 1893, it will be recalled, four aerodromes, known as Nos. 0, 1, 2, and 3, had been built, which were of two general types of construction. First, that represented by No. 0, in which a radically weak hull was made to support rods at the front and rear, to which the wings and tail were attached. This aerodrome was abandoned on account of the inability to provide it with sufficient power, as well as because of its constructional weakness. Second, that type represented by Nos. 1, 2, and 3, in which a midrod was carried through from front to rear, around which the hull supporting the machinery was built. These models were much lighter than No. 0, but were all abandoned because it was found impossible to propel even the lightest of them. While all these machines were in the strictest sense failures, inasmuch as none of them was ever equipped with supporting surfaces, yet the experience gained in the construction of them was of the very greatest value in determining the points at which strength was needed, and in indicating the mode of construction by which strength and rigidity could be obtained.[1]

1893

Another aerodrome, known as No. 4 (shown in Plate 11), was designed in the latter part of 1892, and by the end of March, 1893, its construction was well under way. It was of the second type, in that the midrod was continuous, but it differed from the preceding forms in having the machinery (boilers, burners, and tanks) attached directly to the midrod, the hull now taking the form of a mere protective sheathing. As in Nos. 2 and 3, two engines were used, which were mounted on a cross-frame of light tubing attached to the midrod at right angles. It had, as at first constructed, no provision for the generation of steam, but only for carrying a reservoir of carbonic acid to supply gas for the engines.

The whole, including wings, tail, and engines, but without the carbonic acid reservoir, weighed 1898 grammes (4.18 lbs.). A cylindrical reservoir, weighing 521 grammes (1.14 lbs.) and capable of holding 1506 cu. cm. (92 cu. in.) was constructed for this purpose, and tested for 30 minutes with a pressure of 100

[1] It is to be remembered that these aerodromes were under incessant modifications, No. 4 for instance, presenting successive changes which made of it in reality a number of different machines, one merging by constant alterations into the other, though it still went under the same name. After 1895 the type of the models remained relatively constant, but during the first five years of the work, constructions equal to the original building of at least eight or ten independent aerodromes were made.

atmospheres. If the weight of the cylinder, with its contents and adjuncts, be taken as 800 grammes (1.76 lbs.), the total weight of the aerodrome was 2698 grammes (5.95 lbs.). The wings were plane surfaces of silk, stretched over a very light frame, with no intermediate ribs to prevent the wing from being completely distorted by the upward pressure of the air. Even if they had been sufficiently strong and stiff, the total surface of both wings and tail was but 2601 sq. cm. (2.8 sq. ft.) or approximately 0.5 sq. ft. of supporting surface to the pound, much less than was found adequate, even under the most favorable circumstances. The weight was much more than had been contemplated when the wings were designed, yet, if all the other features of the aerodrome had been satisfactory, and sufficient power had been secured, the work of providing suitable supporting surfaces would have been attempted. But as it was found that the engines when supplied with carbonic-acid gas were unable to develop anything like the power necessary to propel the aerodrome, and that the construction could be greatly improved in many other ways, this aerodrome was entirely rebuilt. The work of the engines with carbonic acid had been so completely unsatisfactory that the idea was entirely abandoned, and no further attempts to develop an efficient motor other than steam were made.

It now became realized more completely than ever before that the primary requisite was to secure sufficient power, and that this could be obtained only by the use of steam. This involved a number of problems, all of which would have to be solved before any hope of a successful machine could be entertained. In the first place, engines of sufficient power and strength, but of the lightest possible construction, must be built. Second, a boiler must be constructed of the least possible weight, which would develop quickly and maintain steadily steam at a high enough pressure to drive the engines. This demanded some form of heating apparatus, which could work under the adverse condition of enclosure in a narrow hull, and steadily supply enough heat to develop the relatively large quantity of steam required by the engines.

The first of these problems, that of procuring suitable engines, was at least temporarily solved by the construction of two engines with brass cylinders, which had a diameter of 2.4 cm. (0.95 in.), and a piston stroke of 5 cm. (1.97 in.). The valve was a simple slide-valve of the piston type, arranged to cut off steam at one-half stroke. No packing was used for the piston or the valve, which were turned to an accurate fit to the cylinder and the steam-chest respectively. In the engines built up to this time, the parts had frequently been soldered together, and a great deal of trouble and delay had arisen from this cause. In these new engines, however, as strong and careful a construction was made as was possible within the very narrow limits of weight, with the result that the engines, though by no means as efficient as those constructed later, were used in all the experiments of 1893 and also during the first part of 1894.

As soon as these engines were completed, in February, 1893, a test was made of one of the cylinders, steam being supplied from the boiler of the shop-engine. The experiments were made with the Prony brake, and showed that at a speed of 1000 revolutions per minute, the power developed from a single cylinder was 0.208 H. P., with a mean effective pressure in the cylinder of only about 21 pounds per square inch of piston area, allowing a loss of 25 per cent for the internal resistance of the engine. This pressure was so much less than should have been obtained with the steam pressure used, that it now seems evident that the steam passages and ports were too small to admit and exhaust the steam with sufficient rapidity to do the work with the same efficiency that is obtained in common practice. This, however, was not immediately recognized. The piston speed at 1000 R. P. M. was 328 feet per minute, at which speed the steam at a pressure of 80 pounds should have been able to follow up the piston and maintain almost, if not quite, full boiler pressure to the point of cut-off, but it did not do so.

The problem of generating steam was much more difficult and required a long and tedious series of experiments, which consumed the greater part of the year before any considerable degree of success had been attained. In the course of these experiments many unexpected difficulties were encountered, which necessitated the construction of special forms of apparatus, which will be described at the proper point. Numerous features of construction, which seemed to be of value when first conceived, but which proved useless when rigorously tested, will be noted here, whenever a knowledge of their valuelessness may seem to be of advantage to the reader.

The boiler was necessarily developed simultaneously with the development of the heating apparatus, and in the following pages, as far as possible, they will be treated together; but often for the sake of clearness and to avoid repetition, separate treatment will be necessary.

At the beginning of these experiments, there was much doubt as to whether alcohol or gasoline would be found most suitable for the immediate purpose. An alcohol burner had been used in connection with the earliest aerodrome, No. 0, but from the results obtained with it at that time, there seemed to be little reason to hope for success with it. It is to be premised that the problem, which at first seemed insoluble, was no less than to produce steam for something like 1 H. P. by a fire-grate, which should occupy only a few cubic inches (about the size of a clenched hand) and weigh but a few ounces. It had to be attacked, however, and as alcohol offered the great advantage of high calorific properties with freedom from all danger of explosion, it was at first used.

Early in 1893, it occurred to me to modify the burner so as to make it essentially an aeolipile, and in April of that year the first experimental aeolipile model shown at *A* (Plate 12) was made. It was very small and intended for the dem-

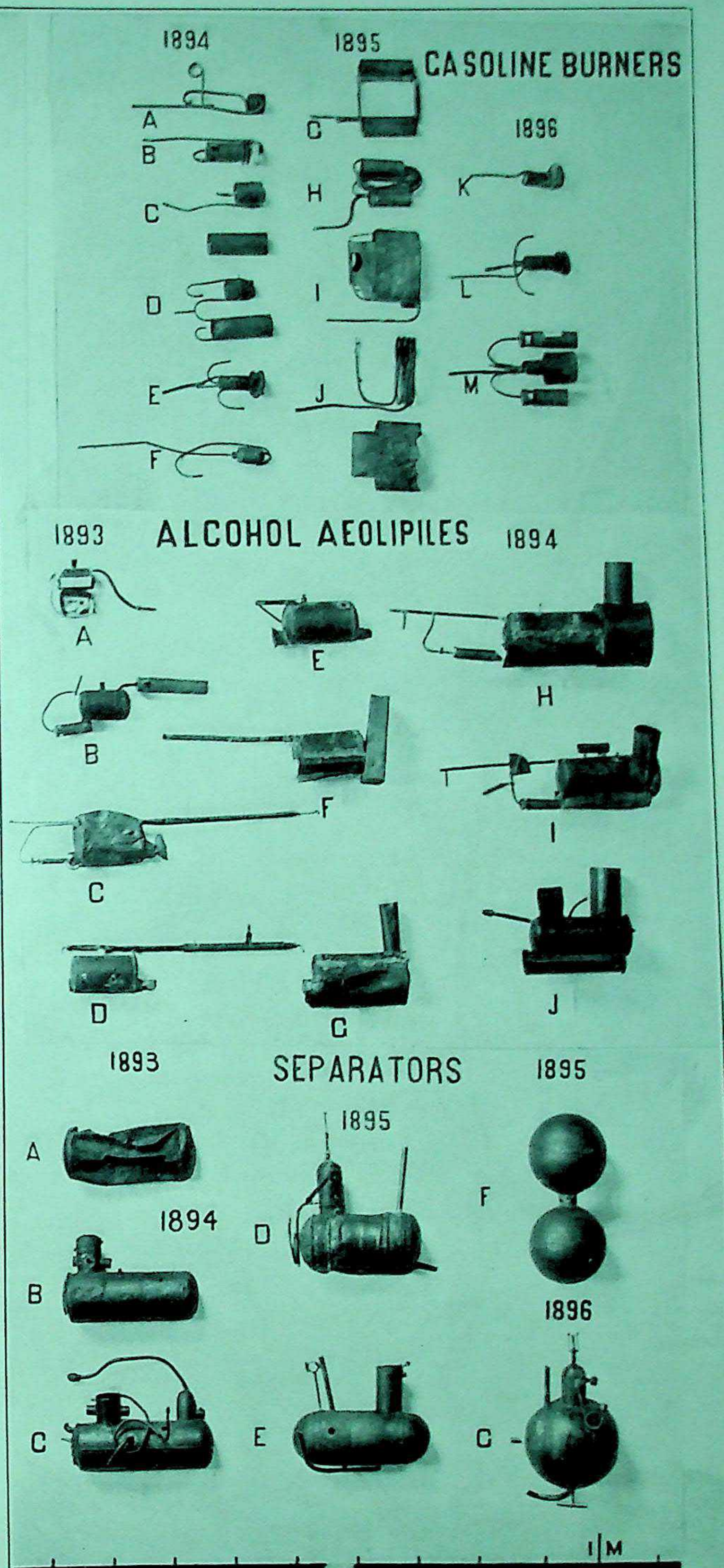
onstration of a principle rather than for actual service, but the construction of this small aeolipile was an epoch in the history of the aerodrome. It furnished immensely more heat than anything that had preceded it, and weighed so little and worked so well that in May the aeolipile marked *B* was made. In this design two pipes were led from the upper portion of the cylinder, one to a large Bunsen burner which heated the boiler, the other to a small burner placed under the tank to vaporize the alcohol. This was followed by the one shown at *C*, wherein the heating burner was smaller and the gas pipe, leading to the main burner, larger.

Figures *D, E, F,* and *G* (Plate 12) were really continuations and improvements of the same idea. In *C* there was simply a tube or flue through the tank; in *F*, however, this tube discharged into a smoke-stack fastened to the end of the cylinder, while in *G* the flue turned upward within the tank itself and discharged into the short stack on top. The object of these changes was to increase the draft and heating power of the small flame, so that the gas would be more rapidly generated and a greater quantity be thus made available for use under the boiler in a unit of time. They were, however, though improvements in a construction which was itself a great advance, still inadequate to give out a sufficient amount of heat to meet the excessive demands of the required quantity of steam. The boilers in connection with which these aeolipiles were used must now be considered.

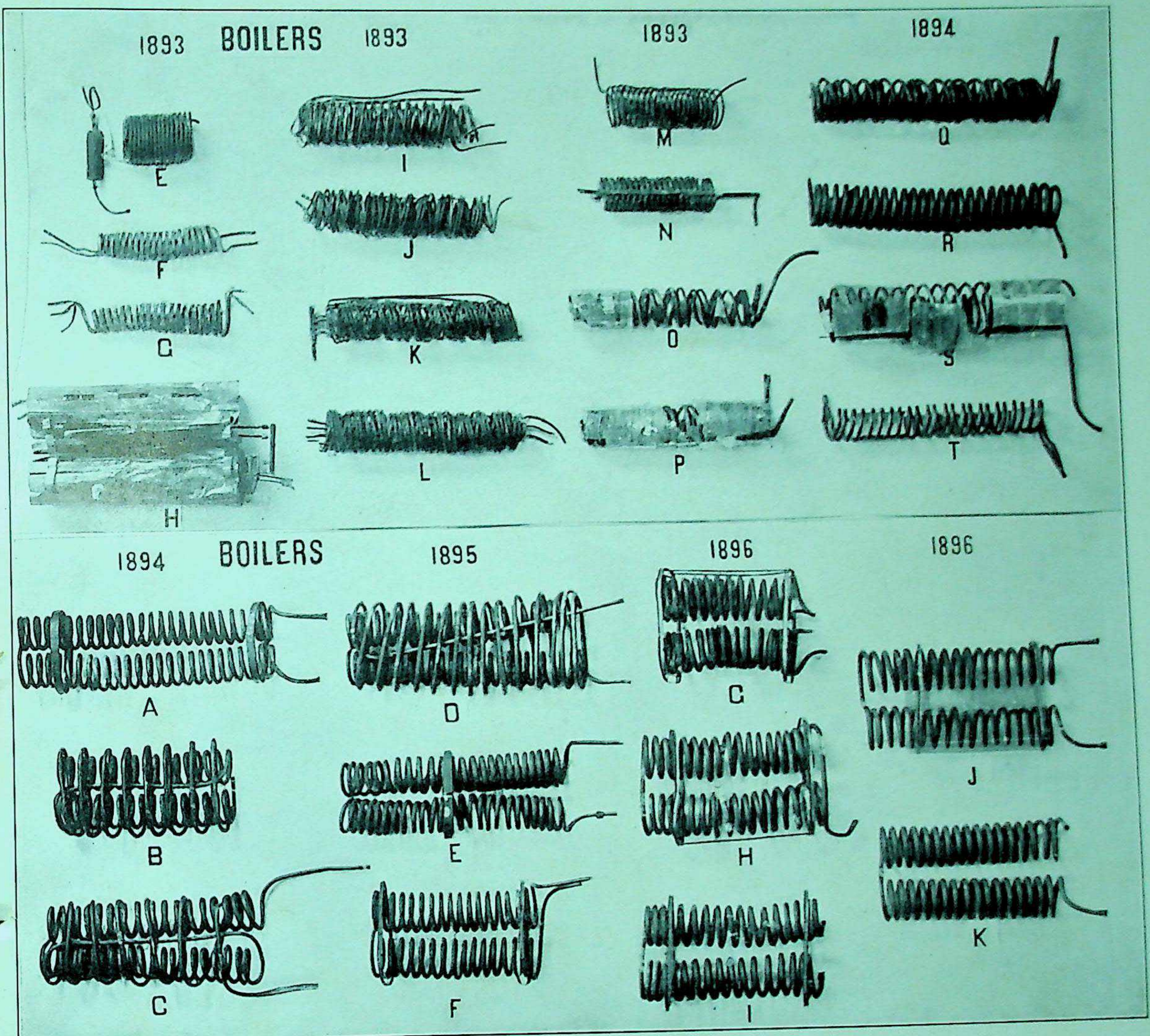
The first boiler *E* (Plate 13) made during this year was a double-coil boiler of the Serpollet type, formed of 19 feet of copper tubing having an internal diameter of about $\frac{1}{8}$ inch. Attached to the boiler was a small vertical drum, from the top of which steam was led to the engine, a pipe from the bottom leading to the pump. This boiler was tested in April with an alcohol heater, the pump in this trial being worked by hand. This apparatus developed a steam pressure varying from 25 to 75 pounds, which caused the engines to drive a 60 cm. propeller of 1.25 pitch-ratio 565 revolutions per minute. The greatest difficulty was experienced in securing a sufficient and uniform circulation in the boiler coils. The action in the present case was extremely irregular, as the pressure sometimes rose to 150 pounds, driving the engines at a dangerous speed and bending the eccentric rod, while at other times it would fall so low that the engines stopped completely.

As the pump used in this trial had proved so unsatisfactory and unreliable, it was replaced by a reservoir of water having an air-chamber charged to 10 atmospheres, the flow from which could apparently be regulated with the greatest nicety by a needle valve at the point of egress; but for some reason its performance was unsatisfactory and remained so after weeks of experiment.

There was used in connection with this device the double-coil boiler shown at *F* (Plate 13) which was made of tubes flattened so as to be nearly capillary. The idea of this was to obtain a larger heating surface and a smaller volume of



BURNERS, AEOLIPILES, AND SEPARATORS



BOILERS OF AERODROMES

water, so that by proper regulation at the needle valve, just that quantity would be delivered which could be converted into steam in its passage through the coils, and be ready for use in the engines as it left the boiler at the farther extremity. The results obtained from this were an improvement over those from the original coil, and a third set of coils (*G*, in Plate 13) was made. This boiler consisted of three flattened tubes superposed one over another.

These two boilers were tried by placing them in a charcoal fire and turning on an alcohol blast, while water from a reservoir under constant air pressure was forced through them past a pin valve. The result was that the two-stranded coil supplied steam at from 10 to 40 pounds pressure to run the engines at about 400 revolutions per minute. The pressure rose steadily for about 40 seconds and then suddenly fell away, though the coils were red-hot, and neither the water nor the alcohol was exhausted—apparently because of the irregularity of the supply of water, due to the time taken by it after passing the valve to fill the considerable space intervening between that point and the boiler.

An attempt was made to overcome this difficulty by putting a stop-cock directly in front of the boiler so that the water, while still under the control of the needle valve, could be turned in at once; the alcohol blast was also arranged to be turned on or off at pleasure, and provision was made, by taking out the end of the flue inclosing the boiler, to provide for an increased air supply. With this arrangement a flame eight or nine inches long was obtained, but a test showed that not more than 25 grammes of water per minute passed through the tubes, which was not enough.

Further tests with these boilers were so far satisfactory as to show that with the flattened-tube Serpollet boiler, comprising from 60 to 80 feet of tubing, from 80 to 100 pounds pressure of steam could be maintained, but not steadily. As there were difficulties in flattening the tubes to make a boiler of this sort, a compromise was effected in the construction of the one shown at *H* (Plate 13), which was made of light copper tubes 5 mm. in diameter, laid up in three lengths of 6 metres each. The ends of these coils were so attached to each other that the water entering at one end of the smallest coil would pass through it and then enter the middle coil, whence it passed through the third or outer coil. Two sets of these coils were made and placed in the thin sheathings shown in the photograph. Repeated experiments with these boilers demonstrated that the pressure did not rise high enough in proportion to the heat applied, and that even the pressures obtained were irregular and untrustworthy. The principal difficulty still lay in maintaining an active and uniform circulation through the coils, and for this purpose the water reservoir under constant air pressure had proved itself inadequate. This pointed to a return to the use of the force pump, the construction of which had hitherto presented so many special difficulties that it had been temporarily abandoned.

A further difficulty experienced in the use of these boilers had been that of obtaining *dry* steam for the engines, as during the early experiments the steam had been delivered directly into the engines from the boiler coils. But in August the writer devised a chamber, known as the "separator," where it had an opportunity to separate from the water and issue as dry steam, or at least approximately dry steam. This was an arrangement familiar in principle to steam engineers under another form, but it was one of the many things which, in the ignorance of steam engineering the writer has already freely admitted, he had to reinvent for himself.

At about the same time, a new pump was designed to drive the water from the bottom of the separator, which served the double purpose of steam drum and reservoir, into the coils. This pump had a diameter of 4.8 cm., and was run at 180 strokes per minute.

The result of the first experiments with these improvements demonstrated that, within certain limits, the amount of water evaporated is proportional to the circulation, and in this boiler the circulation was still the thing that was at fault. Finally, the results of the experiments with the two-stranded, triple-coil boiler may be summed up in the statement that it was possible to maintain a pressure of 80 pounds, and that with it the engines could be made to develop from 0.3 to 0.4 H. P. at best. It weighed 650 grammes (1.43 pounds) without the asbestos jacket.

About this time the writer had the good fortune to secure the temporary services of Dr. Carl Barus, an accomplished physicist, with whose aid a great variety of boilers were experimented on.

The next form of boiler tested was that shown at *N* (Plate 13), made on a system of coils in parallel, of which there were twenty complete turns. In the first test it generated but 20 pounds of steam, because the flame refused to work in the colder coils. The work of this boiler was very unsatisfactory, and it was only with the greatest difficulty that more than ten pounds pressure could be maintained. There was trouble, too, with the circulation, in that when the flame was in full play the pump seemed to meet an almost solid resistance, so that it could not be made to do its work.

A new boiler was accordingly made, consisting of three coils of four strands each. With this the pump worked easily, but whereas it was expected to get 120 pounds pressure, the best that could be obtained was 70 pounds. The outer coil was then stripped off, and a trial made in which everything ran smoothly and the pressure mounted momentarily to 90 pounds. After some adjustment, a mean pressure of 80 pounds was obtained, giving 730 revolutions of the engine per minute, with an indicated horse-power of 0.32.

It was shown in this work that, within certain limits, steam is generated most rapidly when it is used most rapidly, so that two engines could be used

almost as well as one, the reason apparently being that the rapid circulation increased the steam generating power of the boiler, and that the engines worked best at about 80 pounds. It was also found that a larger tubing was better than the small, weight for weight, this fact being due to the greater ease with which circulation could be maintained, since fewer coils were necessary in order to obtain the same external heating surface. The pressure in the coils and the separator was also much more nearly equalized. The result was that the boiler temporarily approved was one made of tubing 6.35 mm. (0.25 inch) in diameter, bent into a two-coil, two-stranded boiler, having sixteen complete turns for each strand in each coil. The total weight was 560 grammes (1.23 pounds) with a total heating surface of 1300 sq. cm. (1.4 sq. ft.).

The separator used in the experiments made during August and September was of a form in which the water was forced below a series of partitions that prevented it from following the steam over into the cylinders of the engines. It weighed 410 grammes (0.9 pound) and was most conveniently worked with 700 grammes (1.54 pounds) of water. The boiler and separator together weighed 970 grammes (2.1 pounds).

A new separator was, however, designed, which was horizontal instead of vertical, as it was intended that it should be placed just below the midrod. Another form, devised for constructional reasons, consisted of a cylinder in which a pump was imbedded. Heretofore the pump used had been single-acting, but it was now proposed to make a double-acting pump. Upon testing this apparatus, it was found that when using an aeolipile, it took 150 grammes of alcohol to evaporate 600 grammes of water. It was evident that the latter was used very wastefully, so that the thermal efficiency of the engine was not over one per cent; but it was also evident that, under the necessity of sacrificing everything to lightness, this waste was largely inevitable.

About the middle of October, another boiler (O, Plate 13) was made, which consisted of two coils wound in right and left hand screw-threads, one fitting loosely over the other, so as to make a cylindrical lattice-work 32 cm. (12.6 in.) long. Each coil contained two strands of copper tube 0.3 mm. thick, and weighing 54 grammes to the metre (0.036 pound to the foot). The inner coil had a diameter of 5.63 cm. (2.22 in.), with nine turns of tube to the strand, the two strands making a length of 319 cm. (10.5 feet) for the coil. The outer coil had a mean diameter of 6.88 cm. (2.71 in.) and a length of 388 cm. (12.7 feet) for the two strands. The total length of the two coils was, therefore, 707 cm. (23.2 feet), with a heating surface of about 1415 sq. cm. (1.52 sq. ft.) and a total weight of 382 grammes (0.84 pound).

The results obtained with this boiler were so far satisfactory as to show that, under the most favorable conditions, when air was supplied in unlimited quantities and there were no disturbing currents to put out or interfere with the work

of the burners, steam could be supplied at a sufficient pressure to run the engines. It was realized, however, that the conditions in flight would be very different, and that in order to protect the apparatus from the wind, some sort of protecting covering would have to be devised, which would of itself introduce new difficulties in providing the burners with a proper and uniform draft.

The hull, as at first constructed, consisted of a cylindrical sheathing open in front, through the rear end of which the boiler and aeolipile projected inward,

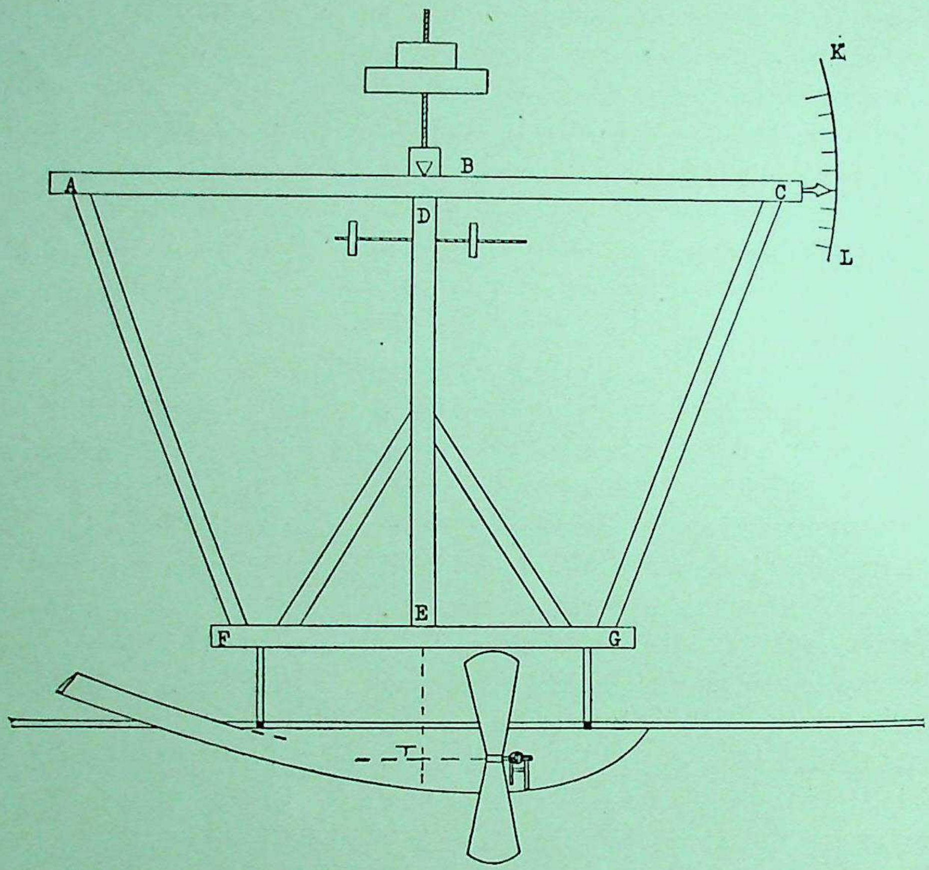


FIG. 10. Diagram of pendulum.

so that the air taken in at the front would be drawn through the boiler and hearth to the exclusion of lateral currents. In the first tests, however, after the hull had been applied, it was impossible to secure a proper rate of combustion, nearly the whole hull being filled with a bluish flame, while only a very small portion of the gases of combustion passed into the coils of the boiler. The remedy for this lay in obtaining an increased draft, and a small stack was, therefore, arranged to carry off the products of combustion. This proved inadequate, and it was only after several weeks of experiment with various types of smoke-stack, and constant alteration of the aeolipile, that it was possible to make the apparatus work effi-

ciently when it was inside the hull. Finally such a degree of success was attained that the burners could be kept lighted even when the aerodrome was placed in a considerable artificial breeze, created by a blower in the shop.

In connection with these tests of the engines and boilers, some method was desired, in addition to the Prony brake tests, by which the thrust of the propellers when driven by the engines at various speeds could be measured accurately and in terms which would be readily available in judging whether the aerodromes were ready to be given an actual trial in free flight. Such a method was found in the use of an apparatus known as the " pendulum," which was introduced near the end of 1892, but was not generally used until the end of 1893. After this time, however, this test was made a condition prerequisite to taking any of the aerodromes into the field, and proved of the greatest assistance in estimating the probable outcome of the trials.

The apparatus used, which is diagrammatically shown in Fig. 10, was extremely simple both in theory and operation. It consisted primarily of a horizontal arm *AC* carrying the knife-edge *B* by which it is pivoted on each side on supporting beams not shown. Depending from *AC* is the light vertical arm *DE*, rigidly joined to it and carrying the lower horizontal arm *FG*, all of which are braced together so as to maintain the arm *DE* constantly perpendicular to *AC*. To this arm *FG* the model was rigidly attached with its center of gravity in line with the vertical arm *DE* and its weight increased by the addition of properly disposed flat weights, in order to make the angle of lift for a given thrust of the propellers smaller and less likely to interfere with the working of the boiler and separator.

Before the actual test of the " lift " could be made, it was necessary to know the exact distance of the vertical center of gravity of the model and the extra weights from the knife-edge *B*. This was determined by the following method: A known weight was suspended from the arm *AB* at some arbitrarily selected distance from the point *B*. This weight caused the perpendicular arms *AB* and *DE* to rotate through an angle, θ, which was measured on the scale *KL*. Knowing, then, the weight on the arm *AB*, its point of application, the weight of the aerodrome suspended on the arm *DE*, and the angle of rotation, it is easy, by a simple application of trigonometric functions, to determine the distance of the center of gravity of the model from the point *B*.

In a test of Aerodrome No. 6 made on September 23, 1898, the weight suspended from *AB* was 10,000 grammes, its point of application 50 cm., the model was weighted to 20,450 grammes, and the angle of rotation, θ, was 7° 2′. Letting y equal the distance of the *CG* from *B*, we may equate the balanced forces thus:

$$10{,}000 \times 50 \cos 7^\circ\, 2' = 20{,}450 \times y \sin 7^\circ\, 2'$$

$$10{,}000 \times 50 \cot 7^\circ\, 2' = 20{,}450\, y$$

$$y = 198.2 \text{ cm.}$$

Having determined this distance, the weight on AB was removed and the aerodrome was allowed to regain its former position. The distance of the center of thrust from B was then measured. The engine was next started and the number of revolutions of the propellers counted by a tachometer. The thrust of the propellers, acting perpendicularly to the arm BD, produced rotation around the point B, the angle of which was measured as above.

In the power test of No. 6, the following data were obtained:

W=weight of aerodrome=20,450 grammes.

θ=angle of lift=19° 30′.

Distance of CG from center of rotation=198.2 cm.

Distance of center of thrust from center of rotation=186.3 cm.

As the propeller thrust and the weight of the model are forces acting in opposite directions at known distances from a center of rotation, letting L equal the "dead lift," we may express the equation thus:

$$W \sin \theta \times 198.2 = L \times 186.3,$$

$$L = \frac{198.2}{186.3} \times \sin 19^\circ\ 30' \times 20{,}450,$$

$$L = 7{,}263 \text{ grammes "dead lift."}$$

The flying weight of Aerodrome No. 6 was 12,064 grammes, and the per cent of this weight lifted was, therefore,

$$\frac{7{,}263}{12{,}064} = 60.3.$$

This was much more than was necessary for flight, but in order to insure successful flights and avoid delay, the rule was made in 1895 that no aerodrome was to be launched until it had previously demonstrated its ability to generate enough power to maintain for at least two minutes a lift of 50 per cent of the total flying weight. At the same time other important data were obtained, such as the steam-pressure, the time required to raise sufficient steam, the total time of the run, and the general working of the boilers and engines.

As will easily be seen, these tests afforded a most satisfactory basis of judging what the aerodromes might be expected to do in actual flight if the balancing were correct.

At this time, October, 1893, the aerodrome (Old No. 4) was practically complete, and the most anxious thought was given to lightening it in every way consistent with the ever-present demand for more power, which necessitated an increase in the weight of both burners and boilers to supply the requisite steam.

On November 14, when the aerodrome was prepared to be shipped to Quantico for trial, its condition was about as follows. The steam-generating apparatus—the parts of which were of substantially the forms last described, although some slight improvements had been introduced—had been developed to

such a point that a pressure of from 70 to 80 pounds of steam could be maintained for 70 seconds, when it was tested in the shop. What it would do under the unfavorable conditions imposed by flight was to be learned only by trial.

At this pressure, the engines, the efficiency of which had been increased by an improvement in packing, would develop approximately 0.4 indicated H. P., while at 105 pounds pressure they at times developed as much as 0.8 H. P. When the aerodrome was tested on the pendulum, these engines, when making less than 700 revolutions per minute, lifted over 40 per cent of the total flying weight.

The propellers used at this time were accurate helices, having a diameter of 60 cm., a width of blade of approximately 36 degrees, and a pitch-ratio of 1.25. They were formed of wood, and were bushed with brass where they were attached to the shafts.

AERODROME OLD NO. 4 AS PREPARED FOR FLIGHT BEFORE BEING SHIPPED FOR TRIAL ON NOVEMBER 14, 1893

Part.	Copper.	Steel.	Brass.	Iron.	Wood and silk.	Mica and asbestos.	Fluid.	Total and mean weights.	
	gms.	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	
Aeolipile	200	..	92	..	..	..	..	292	
Boiler	350	..	37	..	..	..	..	387	
Separator and pumps	300	30	100	20	..	..	..	450	
Engine and frame	..	350	570	..	..	..	..	920	
Midrod (200 cm. long)	..	220	..	..	..	..	..	220	
Two smoke-stacks	70	..	..	..	..	..	..	70	
Asbestos jacketing	..	..	..	..	..	50	..	50	
Air chamber	..	..	..	82	..	..	..	82	
Spider between boiler and burner	32	..	..	..	..	..	..	32	
Intake valve	..	..	15	..	..	..	..	15	
Total	952	600	814	102	..	50	..	2518 =	5.54 lbs.
Hull	50	..	50	..	..	25	..	125	
Pins for starter	..	15	..	..	..	..	..	15	
Two large wings and tail	..	..	..	..	571	..	..	571	
Buffer and steerer	..	..	..	..	53	..	..	53	
Propellers	..	..	..	..	250	..	..	250	
Total	50	15	50	..	874	25	..	1014 =	2.23 lbs.
Grand total	1002	615	864	102	874	75	..	3532 =	7.77 lbs. I.
Density	8.9	7.8	8.5	7.5	0.8	3.0	..	2.48	
Volume (cu. cms.)	113	79	102	136	1092	25	..	1425 =	87 cu. ins.
Alcohol	..	..	..	..	..	..	100	100	
Water	..	..	..	..	..	..	500	500	
Total	..	..	..	..	..	..	..	4132 =	9.1 lbs. II.
Density	..	..	..	..	..	..	{125 / 500}	2.01	
Volume (cu. cms.)	..	..	..	..	..	..	..	2050	

Permanent air spaces:

in midrod, vol. = 355 cc.
in engine frame, vol. = 100 cc.
volume as per II. 2050 cc.
2505 cc.

$$\text{Density} = \frac{4132}{2505} = 1.65 \Big\} \text{III.}$$

The total flying weight of Old No. 4, including fuel and water, was 4132 grammes (9.1 lbs.), a much larger weight than had been contemplated when the original designs were made. A detailed statement of the weights of the various parts of the aerodrome, together with some data as to its density, is given on the preceding page. There were provided in the wings and tail approximately 2 sq. ft. of supporting surface to the pound of weight, which would have been barely sufficient to sustain the aerodrome, even if it had been successfully launched and the wings had been built much stronger than the flimsy construction in use at this time.

An air chamber, which served the double purpose of floating the aerodrome and of providing a moveable weight by which the center of gravity could be shifted to the proper position relatively to the center of pressure, was constructed of the thinnest sheet-iron and attached to the midrod.

This aerodrome, the fifth in actual construction, and the first, after years of experiment, to be carried into the field, was transported to Quantico, where the first trial with it was made on November 20, under the conditions described in Chapter IX.

1894

The aerodrome, No. 4, which has just been described, had not been put to the test of an actual flight, for reasons connected with the difficulties of launching, which are more fully described elsewhere; but, when the completed machine was more fully studied in connection with the unfavorable conditions which it was seen would be imposed on it in trials in the open air, many possibilities for improvement presented themselves. It was seen, for instance, that a better design might be made, in which the engines, boiler and aeolipile might be placed so that the center of gravity of each would lie in the same vertical plane as the central line of the aerodrome. In order to do this the construction of a single midrod, which was the distinguishing feature of Old No. 4, had to be essentially departed from, the midrod of this new one, No. 5, being opened out into two rods, so to speak, which were bent out so that the open space between them furnished a sufficiently large hull space to hold the entire power generating apparatus. In arranging the machinery within this hull, it was provided that, as the water and fuel were expended, the center of gravity of the aerodrome would shift little, and, if at all, backward relatively to the center of pressure.

Instead of the two small engines, which it will be remembered were mounted on the cross-frame in No. 4, a single engine with a larger cylinder, having a diameter of 3.3 cm. (1.3 in.) and a stroke of 7 cm. (2.76 in.), capable of developing about 1 H. P. was used. This engine was mounted within the hull near the forward end and drove the propellers by suitable gearing.

In addition to these radical changes many important improvements were made in the different parts. Internal compartments were built in the separator, so that even if the water was displaced by the pitching of the aerodrome, it could still perform its functions properly The pump was provided with a ratchet, so that it could be worked by hand after the burners were lighted, and before enough steam had been raised to enable the engine to run it. An active circulation was thus maintained in the coils of the boiler as soon as the burner was lighted and before the engine was started, which prevented the tubing from being burnt out, as had frequently happened previously. The wing construction was also improved and many other changes were introduced, which will be treated separately.

In the meantime, No. 4, which had been damaged in the attempted launching in November, 1893, was strengthened and prepared for another trial which took place in January, 1894.

By the end of the first week in February, the engine of No. 5 was ready for trial, and with a boiler pressure of about 80 pounds per square inch, apparently developed 0.56 H. P. on the Prony brake, when making 800 revolutions per minute. To accomplish this called for such good distribution of steam in the cylinder, that it is doubtful if the power could be exceeded at that speed and pressure.

It was, however, apparent that it was desirable to have a boiler capable of supplying steam for at least one horse-power, and that in order to do this, there must be an improvement in the aeolipiles. The problem consisted in arranging to evaporate more than 500 cu. cm., and in fact as nearly as possible 1000 cu. cm. (61 cu. in.) of water per minute, and, since from 200 to 300 cu. cm. per minute had already been evaporated, this was not regarded as impossible of accomplishment. The theoretical advantages of gasoline had for a long time been recognized, as well as the very practical advantage possessed by it of keeping lighted in a breeze, and several attempts had been made during the latter part of the previous year to construct a suitable burner for use with it. These had not been very successful; but in view of the increasing demand for a flame of greater efficiency than that of the alcohol aeolipiles, it was decided to resume the experiments with it.

Accordingly, a gasoline evaporator was tried, consisting in the first experiment of a gasoline tank with nine flues, through which steam was passed. A flow of steam gave a rapid evaporation of gasoline when the pressure did not exceed 5 pounds. The chief difficulty with the burner employed was that the supply of gasoline gas would rise and fall as the steam rose and fell, conditions just the opposite of what was really desired. On the other hand, it was thought that this gasoline tank would form a real condenser for the steam, so that a por-

tion of the exhaust steam would be condensed and be available for use in the boiler again. The gasoline vapor had many advantages over the alcohol; but it was at first possible to evaporate only 120 cu. cm. of gasoline in a minute.

In the experiments that were made at this time (March 9) with gasoline, the main object in view was to obtain a smooth blue flame at 10 pounds pressure. There had been failures to accomplish this, owing to the high boiling point of the liquid, and while the work was in progress it was still evident that the problem of the boiler and the flame which was to heat it had not been solved. A Prony brake test gave, at 130 pounds pressure, 1.1 H. P. with about 1000 revolutions of the propellers; but this was with steam supplied from the boiler of the stationary shop engine.

On April 1, 1894, the following record was made of the condition of Aerodrome No. 5:

> "The wings, the tail, and the two 80 cm. propellers, as well as the two smaller propellers, are ready. The cylinders, gear, pump, and every essential of the running gear, are in place. The boilers, separators, and adjuncts are still under experiment, but may be hoped to be ready in a few days. At present, the boilers give from 450 to 600 grammes of mixed steam and water per minute. With 130 pounds of steam, the engine has actually developed at the brake, without cut-off, considerably more than 1 H. P., so that it may be confidently considered that at 150 pounds, with cut-off, it will give at least 0.8 H. P., if it works proportionately well."

The delays incident to the accomplishment of the work in hand were always greater than anticipated, as is instanced by the fact that it was the latter part of September before the work was actually completed. The greater part of this delay was due to the necessity for a constant series of experiments during the spring and summer to determine the power that it was possible to obtain with the various styles of boilers, aeolipiles, and gasoline burners.

While No. 5 was thus under construction, new and somewhat larger engines had been built for No. 4, the work on them having been begun in January. The cylinders of these engines, which are more fully described in connection with Aerodrome No. 6, were 2.8 cm. in diameter, with a 5 cm. stroke, each cylinder thus having a capacity of 30.8 cu. cm., which was an increase of 36 per cent over that of the old brass cylinder engines, which had previously been used on No. 4. On April 28, under a pressure of 70 pounds, these engines drove the two 60 cm. propellers at a rate of 900 R. P. M., and lifted on the pendulum nearly 40 per cent of the total flying weight of Aerodrome No. 4, which was now approximately 5 kilos. A trial was made at Quantico in the latter part of May, which is described in Chapter IX. It is only necessary to mention in this connection that there was a great deal of trouble experienced with the alcohol aeolipile, the flame being extinguished in the moderate wind to which the aero-

drome was subjected while preparations for the launch were being made. Moreover the flame was so nearly invisible in the sunlight that it was uncertain whether it was burning in the critical instants just before the launch, when doubt might be fatal. These conditions resulted in a final decision in favor of gasoline, on account of its greater inflammability, and in the provision of such hull covering that the fires could be lighted and maintained in a breeze.

In June, I tried a modification of the burner, in which the gasoline was delivered under the pressure of air to the evaporating coil. In the first trial steam was raised to a final pressure of about 70 pounds, and a run of 45 seconds was secured under a pressure of 40 pounds in the gasoline tank, which was thought to be altogether too high; for, at the end of the run, the whole apparatus was enveloped in flames, because of the gasoline that was projected through the burner-tips.

Continual experiments with different forms of burner, illustrated in Plate 12, occupied the time, with delays and imperfect results, which were trying to the investigator, but are omitted as of little interest to the reader. They had, however, the incidental result of proving the practical superiority of gasoline over alcohol, and culminated in the evolution of the burner that was finally used successfully. It consisted of a tank for the gasoline, from which compressed air delivered the liquid to a small coil surrounded by asbestos, in which it was vaporized. At the rear end of this coil three pipes were led off, one of which was a small "bleeder," which fed the burner for heating the gasoline, the other two leading to the main burners. After the generation of gas in the small coil had been started, the heat from the small burner was expected to continue the vaporization, so that nothing but gas would be able to reach the main burners. A device was also introduced, which had greatly increased the amount and uniformity of the draft and consequently made the burners and boilers more efficient than before. This consisted simply in passing the exhaust steam from the engines into the smoke-stack, and it is remarkable that it was not thought of earlier.

By the middle of September, 1894, both aerodromes were completed and ready for another test. On September 27 the condition of Aerodrome No. 4 was as follows: The general type of construction, namely, that of a single midrod, to which all the steam generating apparatus was attached, and which supported also the cross-frame and the wings, was the same as in the construction of 1893. On account of the increased weight of the model, and the substitution of an inferior piece of tubing in place of the former midrod, it was found necessary to stiffen it by the use of temporary trusses. Permanent bearing points for holding the aerodrome securely to the newly devised launching apparatus were also attached to this midrod.

The engines in use at this time were the small steel cylinders described above, which were mounted on the cross-frame, and drove the propellers directly. These engines were capable of delivering to the propellers, as had been proved by repeated tests, at least 0.66 brake horse-power.

The boiler consisted of two inner coils and an enveloping outer coil, loosely wound and connected in series. The inner coils, each of which had about 17 turns of 8 mm. diameter, 0.2 mm. thick tubing, developed about 80 per cent of the steam; the outer coil of 8 turns, while not exactly useless as a steam generator, afforded an efficient means of fastening the smoke-stack and cover of the boiler, and for attaching the latter to the midrod. This boiler was externally 30 cm. long, 16 cm. wide, and 10 cm. deep, weighing with its cover approximately 650 grammes. The stack for the burnt gases, into which exhaust steam was led from a central jet, was about 1 foot long. At best this boiler was capable of developing slightly over 100 pounds of steam.

The separator was of the form last described, except that the steam dome had been moved toward the front, to prevent the jerk of the launching car in starting from causing water to be pitched over into the engines. It was constructed of sheet aluminum-bronze, and weighed, together with its pump, 580 grammes. The pump, which was double-acting and fitted with ball valves, was capable of discharging 4.5 grammes of cold water per stroke, its efficiency being only about one-half as great with hot water.

The gasoline burner, which had been finally adopted in place of the alcohol aeolipiles, had now been perfected to the form in which it was finally used. Two Bunsen burners of special construction were provided with gasoline gas by the heat of an intermediate accessory burner, which played upon a coil to which all three burners were connected. Gasoline was furnished from a tank made of aluminum-bronze, under an air pressure of about 20 pounds, the fluid being under the control of a screw stop-cock. This tank, which was capable of holding 100 to 150 cu. cm. of gasoline, weighed 180 grammes, and the burners with an outer sheathing weighed 302 grammes.

It was calculated that about 3300 cu. cm. (201 cu. in.) of air space would be required to float the aerodrome in water, and this was supplied by an air chamber, having a capacity of 2700 cu. cm. (165 cu. in.), which could be shifted to adjust the longitudinal equilibrium of the aerodrome, and about 900 cu. cm. (55 cu. in.) of space in the gasoline tank and the midrod. The reel and float, which served to indicate the location of the aerodrome, if for any reason it should be submerged, were in one piece, and so moored that there was no danger of fouling the propellers.

The total weight of the aerodrome was about 6 kilogrammes (13.2 lbs.), or, with a maximum quantity of fuel (850 cu. cm. of water, 150 cu. cm. of gasoline),

less than 7 kilogrammes. From 60 to 90 pounds of steam could be maintained by the boilers for about 2 minutes, at which pressure the engines developed about 0.66 brake horse-power, driving the 70 cm., 1.25 pitch-ratio propellers at 700 R. P. M., and giving a lift of from 2.6 to 3.0 kilos (5.7 to 6.6 pounds), or about 40 per cent of the flying weight.

The wings and tail had a total surface of 2.62 sq. m. (28.2 sq. ft.), giving a ratio of 2.7 kilos to 1 sq. m. of wing surface (1.8 sq. ft. per pound). If the hull resistance be neglected, the soaring speed of this aerodrome was about 5.9 metres (19 feet) per second, or 13 miles per hour.

Turning now to the completed No. 5, its frame was of the "double midrod" type described above, the two tubes which formed the frame being prolonged at the front and rear to afford points of attachment for the wings and tail. The range through which the wings could be shifted to adjust the position of the center of pressure was, however, very small. The hull, which, it will be remembered, contained all the power generating apparatus, was much stronger and heavier than that of No. 4, and resembled somewhat the hull of a ship. It had a frame-work of steel tubing brazed to the midrod, to which an outer sheathing of sheet aluminum 0.3 mm. thick was attached. It was, however, excessively heavy, weighing nearly 800 grammes.

The engine, which was mounted near the front of the hull, was the single cylinder, one horse-power engine, described above, which drove the two propellers by suitable gearing. The remaining parts of the power plant were identical with those already described in connection with No. 4, but the more advantageous location of them in No. 5 rendered them somewhat more efficient.

It had been planned to use 80 cm. propellers of 1.25 pitch-ratio on No. 5, but it was found in the shop tests of the aerodrome that the cross-frame was not strong enough to withstand the strains, and that the engine could be made to work much more steadily with a smaller propeller. Accordingly, propellers of 70 cm. diameter and 1.25 pitch-ratio, similar to those used on No. 4, were finally substituted.

For floating the aerodrome, when it descended into the water, an air-chamber similar to that of No. 4, but of a larger capacity was provided. With this in place on the aerodrome, it was calculated that, if all the parts except this float and the gasoline tank were filled with water, there would still be a buoyancy of over 2 kilogrammes.

The total weight of No. 5 was 8200 grammes, or with its full supply of fuel and water 9200 grammes. In this aerodrome the same boilers used in No. 4 were capable of maintaining for at least a minute 115 pounds of steam, so that the engine now gave the maximum of one brake horse-power for which it was designed, and, driving the 70 cm. propellers, lifted repeatedly nearly 45 per cent of the flying weight.

The wings and tail constructed for No. 5 were identical with those of No. 4, being slightly curved and containing 2.62 sq. m. (28.2 sq. ft.), equivalent to 1.4 sq. ft. to the pound, which with the flimsy construction of the wings gave an entirely inadequate support to the aerodrome.

During the summer a launching apparatus of a new and improved type, which is described in Chapter X, had been perfected, and with it repeated tests were made of both aerodromes in October, November, and December, with the unsatisfactory results recorded in Chapter IX. In the course of these experiments, many slight modifications of the burners and boilers were made, but no important changes were introduced except that the cross-frame of No. 5 was enlarged and strengthened so as to admit of its carrying one metre propellers safely. The results, however, which were obtained, did not compensate for the increased weight of the larger frame.

Viewing the work of this year from the standpoint of results obtained in the numerous attempts at flight, it would seem that very little progress had been made, and that there was small reason to expect to achieve final success. However, if the work be examined more particularly, it will be seen that two of the most difficult problems had been solved, one completely as far as the models were concerned, and the other to a very satisfactory degree. First, a launching apparatus, with which it was possible to give the aerodrome any desired initial velocity, had been devised, and so far perfected that no trouble was ever experienced with it in testing the models. Second, as a result of the extended and systematic series of experiments, which had been conducted under the direction of Dr. Barus, a steam pressure of 115 pounds could be maintained steadily in the boilers for at least a minute, and the burners could be kept lighted even in a considerable breeze.

A summary of these experiments, together with some account of the difficulties encountered and the results finally obtained with the apparatus in use at the end of the year, is given in the following report, which was prepared by Dr. Barus in December, 1894.

"If water be sprayed upon a surface kept in a permanent state of ignition, any quantity of steam might be generated per time unit. Similarly advantageous conditions would be given if threads of water could be passed through a flame. In practice this method would encounter two serious difficulties, the importance of which is accentuated when the boiler apparatus is to be kept within the degree of lightness essential in aerodromics. These difficulties are (1) the danger of chilling the flame below the point of ignition or of combustion of the gases, and (2) the practical impossibility of maintaining threads of water in the flame. For it is clear that the threads must be joined in multiple arc, so as to allow a large bulk of water to circulate through the boiler, whereas even when there are but two independent passages for the water through the furnace, it is hard to keep both supplied with liquid without unduly straining the pump. If the water be even slightly deficient, circumstances will arise in which one of

the passages is better than the other. This conduit will then generate more steam and drive the water under force through the other passage, increasing the temperature discrepancy between them. Eventually the hot passage reaches ignition and either bursts or melts. This is what sooner or later takes place in boilers adapted for flying machines and consisting of tubes joined in multiple arc, when a single moderately strong circulating pump supplies the system.

"To avoid these annoyances, *i. e.*, to increase the length of life of the boiler, the boiler tubes are joined in series to the effect that a single current of water may flow successively through all of them. It is needful therefore to select wide tubes, such as will admit of an easy circulation in consideration of the length of tubing employed without straining the pump and at the same time to allow sufficient room for the efflux of steam. Other considerations enter here, the bearing of which will be seen presently: if the tube be too wide the difficulty of coiling it on a mandrel of small diameter is increased, while at the same time the tube loses strength (*cæt. par.*) in virtue of the increased width.

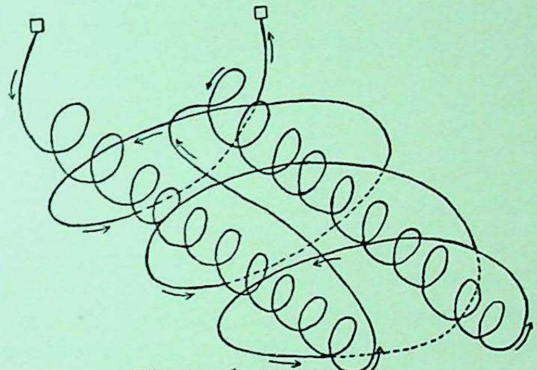


Diagram 1.

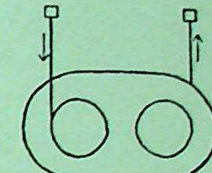


Diagram 2.

FIG. 11.

"It is from considerations such as these that, in the course of many experiments, copper tubing about 8 mm. in diameter has been adopted. Copper is selected because of its freedom from internal corrosion, easy coiling, and because of its availability in the market. The thinnest tube to be had (walls only 0.1 mm. thick) will withstand more pressure than can be entrusted to the larger steam receivers in circuit with the boiler. The boiler weight is thus a negligible factor, and it is quite feasible to reduce the thickness of boiler tubing, by the superficial application of moderately strong nitric acid, to 200-400 grammes per horse-power of steam supplied. External corrosion due to flames occurs only in case of deficient water, and if the boiler be made of tubing with the walls 0.2 mm. thick, it is in view of the possibility of such accidents. Boilers may then be tested to 25 atm. without endangering the metal.

"Boilers are wound or coiled with regard to the two points above suggested, *viz.:* to avoid chilling the flame the successive turns are spaced on all sides, and to bring the water as nearly into the flame as possible, the diameter of the coils is chosen as small as expedient. Further reasons for this will presently be adduced. The type of boiler eventually adopted is shown in the accompanying diagrams, 1 and 2, Fig. 11.

"Diagram 1, is a perspective diagram showing the plan of winding and Diagram 2, an end view. The circulation is indicated. There are two inner coils

each containing about 17 turns, wound on a mandrel 5 cm. in diameter. The turns are spaced so as to allow about 1 cm. clear between successive turns. The outer coil envelopes both, and in this there are about 3 cm. between successive turns, and 8 turns in all. Length, say, 30 cm., breadth 16 cm., thickness 10 cm., give the external dimensions of the boiler. The shell space between outer and inner layers of tubing must nowhere be less than 1 cm. When so wound, the inner coils (here as in other boiler forms) raise about 80 per cent or more of the steam; the outer or enveloping coil, while not quite useless, make the most effective frame work for the boiler jacket which has been devised. The coils are brazed together by blind tubes, as shown in Diagram 2, to keep the whole in shape. Weight with couplings and cover when complete 535 grammes.

" The cover is preferably of mica, through which the flame within the boiler may be seen, and in which lightness, nonconduction, and resistance to the disintegrating effects of high temperature are met with in a pronounced degree. This jacket is held down by copper bands and the end band is continuous with the long smoke-stack, as will presently be shown.

" The wide form of boiler with two coils within the envelope is not absolutely essential. The same amount of steam can be generated from one coil in an envelope in other respects equal to Diagram 1 if a sufficiently hot flame be passed axially through the coils. Such a flame, however, is unstable, and for this reason two milder flames with a good air access are to be preferred on practical grounds even if the weight is thereby increased.

" To further understand the boiler construction it is advisable to consider the action of the flame. Inasmuch as wide tubes must be used, the problem of evaporating water as fast as possible is equivalent to getting heat into the current (water and steam circulating through the coils) as fast as possible from without. If, therefore, t is the mean temperature of the fluids within the coils, and T the effective temperature surrounding the tube, then the rate at which heat will flow into the tubes is proportional to $T-t$. Now t the temperature of the steam is nearly constant (100°-150°) whereas T the effective flame temperature may vary from 800° to, say, 1600°. It is for this reason that the heat sponged up by the boiler depends almost directly on the flame temperature.

" What conditions, therefore, will make the flame effectively hot?

"(1) The coils must obviously be brought as nearly into the flame as feasible: for this purpose the cylindrical helix is better than any other form. But

"(2) The turns and coils must not be so crowded together as to chill the flame into imperfect combustion in various parts of its extent. Hence the loose form of winding. Again

"(3) There must be oxygen enough to allow complete combustion, and

"(4) The flame itself must be hot and the radiation checked by good jacketing.

" To take up the last points: the effective heat of the flame depends not only on the combustion heat of the fuel used; it depends also, among other things, on the speed with which this combustion takes place. A flame burning from a low pressure of alcohol gas will be at low temperature as compared with a flame burning from high pressures of the gas. If the flame be burnt from a Bunsen burner in the usual way it is an interesting question to know how flame temperature will vary with gas pressure. At present we know it merely in steam pressures incidently produced in a given engine (No. 4) as for instance:

$$\left.\begin{array}{l}\text{Flame pressure, 10 lbs., 20 lbs., 30 lbs.}\\ \text{Steam pressure, 40 lbs., 80 lbs., 120 lbs.}\end{array}\right\}\text{in the running engine.}$$

"Unfortunately there is a limit set to this process of increasing the steam supply, quite aside from conditions inherent in the method. This is due to the fact that a certain speed of efflux cannot be exceeded without putting the flame out. Suppose, for instance, in Fig. 12, that a gas generated from a liquid is ignited at the end of the Bunsen burner *F*; then if the velocity of efflux of mixed

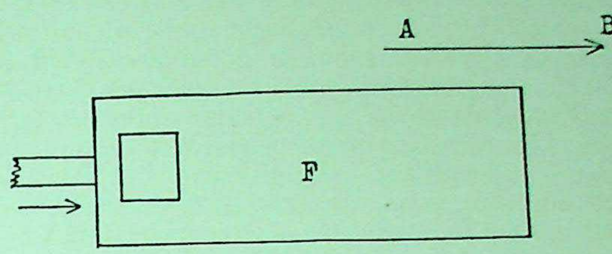


Fig. 12.

gas and air in the direction *AB* from the mouth of *F* exceeds the velocity of combustion in the direction *BA*, the flame will obviously be carried away from the mouth of the tube and dissipated. This state of things is actually realized at pressures exceeding about 15 lbs., depending on the degree of mixture of the combustible gases used, and therefore on apparently haphazard conditions connected with the jet, the air holes, the air supply, etc.

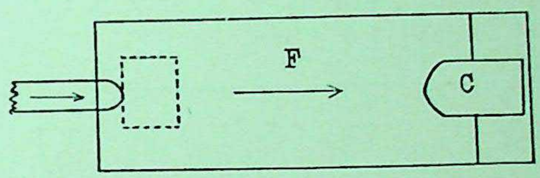


Fig. 13.

"If, however, the velocity of the jet at the point of efflux be checked by an obstruction like a cylinder *C*, Fig. 13, placed co-axially with the burner tube *F*, the speed of combustion will no longer be exceeded (supposing *C* properly chosen) and flames will then burn from high-pressure gas. In this way flames were maintained generated from alcohol gas at even 40 lbs. and above.

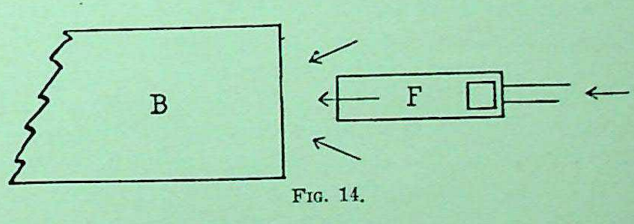


Fig. 14.

"The gas escaping from the Bunsen burner is never sufficiently aërated to burn completely. Otherwise there would (in general) be explosions in the tube *F*. A part of this air is supplied at the mouth of the boiler *B*, Fig. 14, and the amount available here will depend on the velocity of the jet *F*. Hence it does not follow that a high-pressure burner like that in Fig. 11 will supply a proportionate amount of heat, since its jet suction is not intense and the combustion within the boiler is incomplete. This difficulty may be remedied by placing

air holes in the jacket of the boiler, provided the boiler be wrapped loosely enough not to chill the flame below ignition. It is with reference to this effect that the boilers, Fig. 11, were wound. A number of rifts *aaa,* Fig. 15, are then left in the jacket through which air may enter in virtue of the burner flame acting as a jet at the mouth of the boiler.

"When so constructed the flame at first enters the inner coil only; but after a little while it suddenly spreads out throughout the whole interior space and envelops the coils. This sudden expansion is due, probably, to the assumption of the spheroidal state by the water within the coils, the current now flaring on an enveloping cushion of steam. The pump must work well, for deficient water means a hot tube and deficient steam, or eventually a rupture of the tube.

"Thus far the dependence for draft has been on the burner jet and the suction of the smoke-stack in virtue of the inertia of the moving gases. But even with this ventilated boiler, this method is limited to certain dimensions of the boiler. Thus a boiler 80 cm. long yielded about the same quantity of steam as a boiler half as long and otherwise similar. Only the initial parts of the boiler are, therefore, relatively efficient, and the reason of this seems to be that, apart from shape, etc., the flame as a heat-producing agent is practically defunct, when a certain amount of heat has been taken out of it: in other words, even with

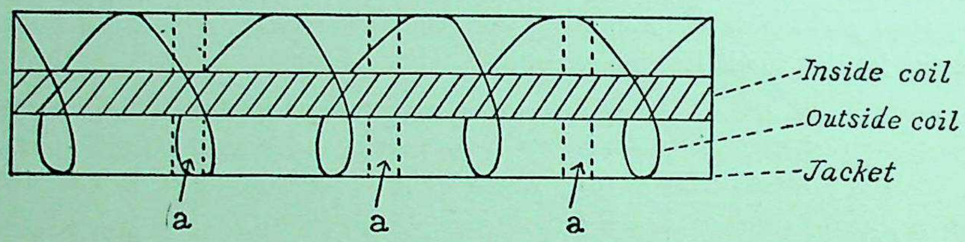


FIG. 15.

fair ventilation the flame is eventually chilled off by the voluminous products of combustion continually accumulating in the boiler. The same choking action accompanies the presence of unburnt gases. If, for instance, the flame be burnt in the air, it is slender and much smaller in volume than in the boiler. The flame is also of small volume and burns completely in a wide boiler, but the steam is always deficient, because of the distance between flame and coils (see above). With the above apparatus about $\frac{1}{2}$ lb. of dry steam per minute per square foot of heating surface was attained.

"This introduces the final condition for rapid steam generation. There must be artificial suction at the smoke-stack. By passing the exhaust steam in the form of a central jet through the smoke-stack the yield of steam was increased 20 to 30 per cent. In fact as the supply of gas from the burner is given, the artificial suction in question means more air in the boiler for the same amount of gas and it means also a more rapid removal of the exhaust gases. The experiments with steam suction are yet to be completed, and with them the boiler question is to be finally laid at rest. The chief points at issue are these:

"1. Seeing that the jet suction increases with the length of the smoke-stack, up to a certain length at least, how long and how wide must the efficient smoke-stack be made? Thus a smoke-stack 10 cm. long is all but useless. Good results are obtained when the stack measures 30 cm. in length beyond the end of the steam jet.

"2. What is the relative efficiency of the initial and final halves of the length of the boiler? This will show in how far it is useful to increase the length of the boiler for a given burner and steam jet. It will also show what advantage is to be gained from triplicate boilers with three burners, as compared with duplicate boilers with two burners, or single boilers with one burner, *when the same weight* of tubing is used throughout.

"3. What is the effect of pressure on the aeolipile tank, or in how far does the steam generated depend on what may be called the pressure of the flame? This is also an important point which remains for quantitative solution. It can be approached in two ways: either by finding the steam evaporated in terms of the tank pressure, or by finding the temperature of the flame pyrometrically.

"4. What speed of water circulation best conduces to steam generation? A good pump is now installed by which the circulation can be varied. If water can be put into the boiler just fast enough to come out dry steam at the other end, the efficiency ought to be a maximum, but it does not follow that it will be so, for one can imagine a wet circulation sponging up more heat than one which is just dry at the end."

1895

During January and February, 1895, the experiments with boilers and burners were continued and even better and more uniform results than those given above were obtained. The boilers of Aerodrome No. 5 were finally brought to such a state of efficiency, that under favorable conditions a lift of nearly sixty per cent of the flying weight was secured. This was much more than was required for flight, but it was decided to postpone the trials until No. 4 could also be made ready for a test and the frame of No. 5 could itself be strengthened in many weak places.

Upon examining No. 4, which had been put aside since the trials in December, it was found to have rusted so badly throughout and to be so unfit in every way for trial, that a complete reconstruction of the whole would be necessary. So many advantages had been gained in No. 5 by the double midrod type of construction that it was decided to rebuild No. 4 on a modification of the same plan, as shown in Plate 11, retaining, however, the same engines which had been used before.

In this a very guarded return was made to the type which had proved so unsatisfactory in No. 0, that is, making the hull support rods at the front and rear for attaching the wings and tail. In this case, however, the hull was constructed very rigidly, and the tubes at the front and rear were firmly attached and braced so that they could withstand a considerable strain without undue distortion. The work on this frame was completed in March, but the other parts were not in entirely efficient condition even in May, when the aerodromes were taken to Quantico for trial. Moreover, it was found that the weight of this aerodrome had increased far beyond the original estimates.

In view of the disasters from trials in the field, due to inability to obtain automatic equilibrium in flight and to the flexure of the large wings rather than to defects of the engines, the conditions at this time, after three years of failure, seemed so nearly hopeless, that without abandoning the work on these steam aerodromes, I again had recourse to the early plan of constructing smaller models driven by India rubber, in which the small wings employed could be made of the requisite stiffness. Instead of employing twisted rubber, however, the defects of which had been amply proved in previous trials, these new constructions were meant to employ rubber directly stretched and pulling. In this condition the rubber exercises nearly six times the power in proportion to weight that it does when twisted, but on the other hand it requires a very strong frame and subordinate parts.

I spent an inordinate amount of time and labor during this year in attempting to employ this latter form of construction and finally got a few useful results from it, but none in proportion to the labor expended.

During March, Aerodrome No. 5, the frame of which had proved on test to be radically weak, was completely refinished except for the wings. The propellers had hitherto been made of wood, but in May, I commenced a new construction of steel, wood and cloth, on a plan giving a figure which, though not rigorously helicoidal, was practically near enough to the theoretical form and was also both lighter and more elastic than the wooden construction.

On May 8 and June 7 Aerodrome No. 5 was again tried at Quantico, and although the tests were unsuccessful, in that the aerodrome failed to fly, partly because of the fact that so much time was spent in raising steam that practically the entire supply of fuel and water was exhausted before the aerodrome was actually launched, yet it had come so much nearer flying than any machine had previously done, that it was felt that if either the power could be increased or the weight decreased even a slight amount, the aerodrome would probably fly. In view of the great care that had been exercised in keeping down the weight, it seemed almost hopeless to attempt to reduce it, and it also seemed equally hopeless to attempt to get more power without increasing the weight. However, something had to be done to increase the ratio of power to weight, and as it was seen that this would involve extensive changes in No. 5, it was decided to entirely rebuild No. 4 with this idea in view, though it was evident that it involved a plan of construction even lighter than the dangerously light plan on which No. 4 had already been constructed.

During Mr. Langley's absence in Europe in the summer, Aerodrome No. 4 was entirely reconstructed and made to embody many new characteristics, the changes introduced being so radical that this model was henceforth designated as "New No. 4." The new characteristics of this model were its unprecedent-

edly light frame and the elevation of the transverse frame 12 centimeters above the midrod, whereby the position of the line of thrust was raised so that it was 20 centimetres from the center of pressure, which from theory seemed to be very nearly its correct position. The total flying weight was but 6400 grammes (14 pounds), with a total supporting surface of fifty-four square feet, equivalent to very nearly four square feet per pound. It was hoped that with this extremely light construction the " dead lift " would amount to a large percentage of the flying weight, and as much as sixty per cent was actually lifted on the pendulum. As, however, the aerodrome approached completion it became more and more evident that the construction was hopelessly fragile, the frame being scarcely able to support itself in the shop. By November this conclusion became certain, and this aerodrome (New No. 4) was never put to an actual test in the field. The very expensive set of wings covered with gold beater's skin, which were also constructed at this time for this model, proved so weak under test that they were entirely abandoned.

When Mr. Langley returned to Washington in the fall, many important points, which had been under special consideration during the past year, particularly those relating to the disposition of sustaining surfaces, and the provision of automatic equilibrium, were still not definitely determined. It was not yet decided whether two sets of wings of equal area should be used for the aerodrome, or what the efficiency per unit of area of the following surfaces was in comparison with the leading surfaces. To aid in determining these and other important points concerning the relative position of the center of gravity and the center of pressure in the horizontal planes, he had several small gliding models made, which could be used with either one or two pairs of wings, and afforded an opportunity for testing and comparing several types of curved surfaces.

These models were built so that the center of gravity could be adjusted to any desired point, and had in addition, as a means of assisting in preserving equilibrium, a small tail-rudder, shaped somewhat like a child's dart, which was intended to support no part of the weight.

The tests with these models were very satisfactory and aided greatly in the final development of what is known as the " Langley type." Indeed, in the single month of November all the points, which had hitherto been more or less indefinite, were finally decided upon, and the tests of the following spring proved these decisions correct.

Two sets of wings of equal area were hereafter provided for every aerodrome, which not only greatly increased the stability, but also overcame the difficulty hitherto experienced in bringing the *CP* over the *CG*. The tail-rudder, formed of planes intersecting at right angles, was adopted as the means of control. In use on the aerodromes it was set at a negative angle, and given a certain

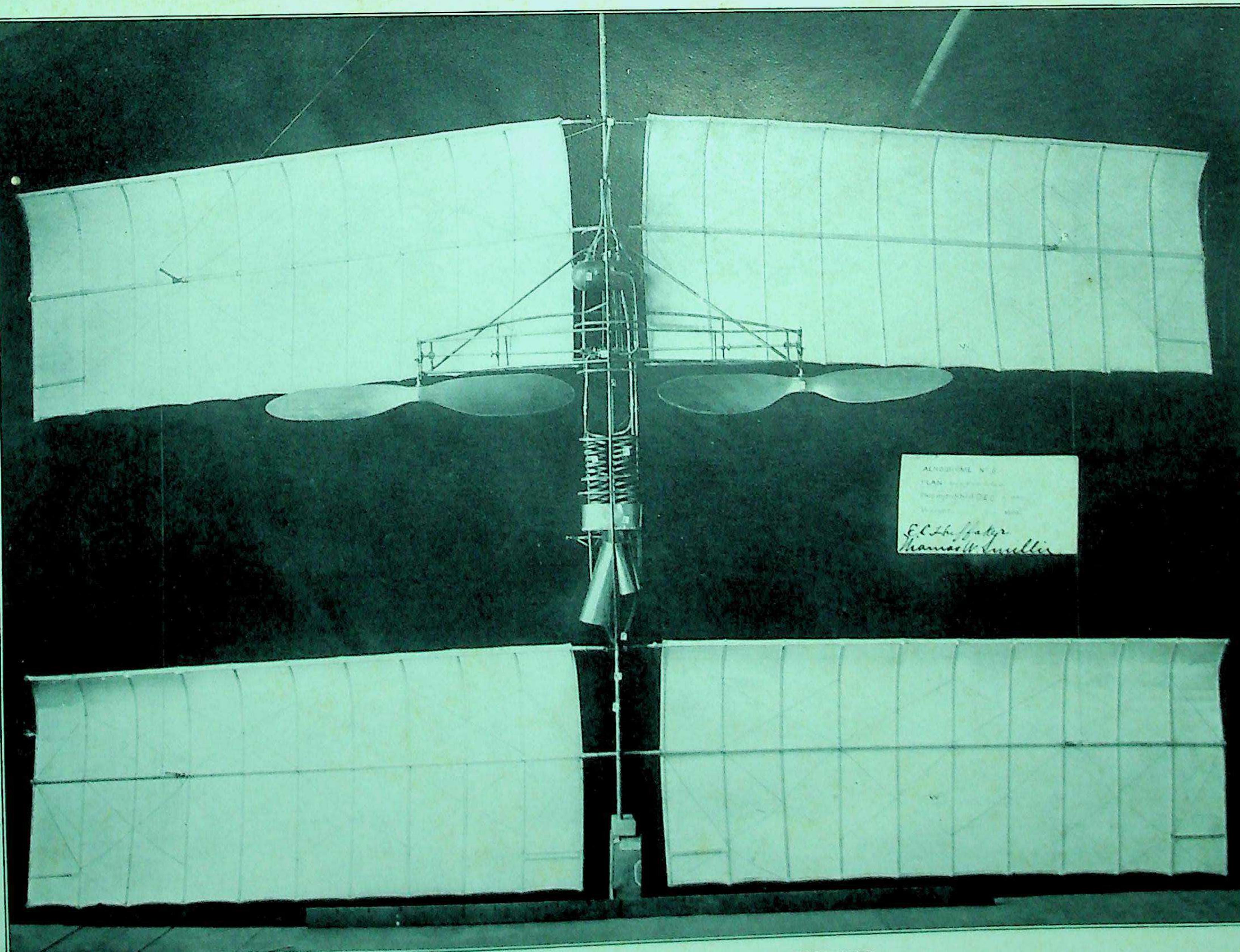
degree of elasticity, which was at first provided in the frame of the rudder, but was later given by a flat wooden spring, by which it was attached to the aerodrome. The tail in this form now became the sole means of controlling the equilibrium, and the results obtained with it were so very satisfactory that no further attention was given either to the gyroscopic control built during the previous summer, or to any of the electrical forms of control constructed prior to that time, all of which involved more or less delicate apparatus.

The definite form into which these ideas crystallized is perhaps best exemplified in the letter of instructions issued by Mr. Langley on November 30, 1895 to the men employed on the work. The text of this letter is given in the Appendix, and the forms referred to in it for recording the weights and adjustments of the aerodromes are those used in the data sheets after this time.

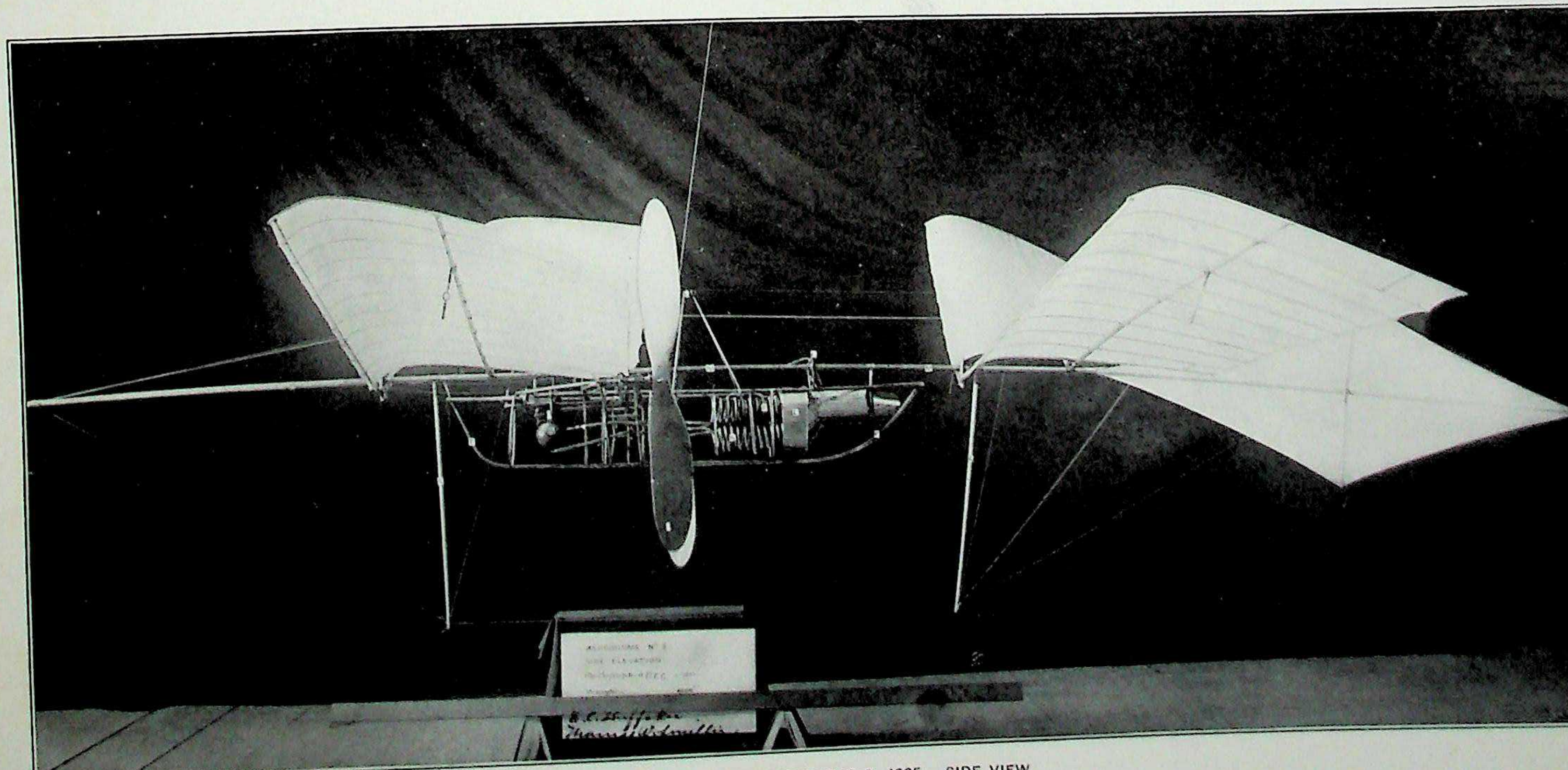
In October work was resumed on Aerodrome No. 5, on which nothing had been done since its test on June 7. The reconstruction of "Old No. 4" into "New No. 4" which had occupied the entire summer, and the final result of which was the production of a machine so radically weak as to be useless, had been so discouraging that it seemed vain to attempt in any way to decrease the weight of No. 5. The addition of the rear wings in place of the tail had, however, so greatly increased the supporting surface that it seemed possible that No. 5 might now be able to fly with no greater engine power than it had on June 7. Some weak places in its frame were, therefore, strengthened and the midrod at the front was raised five centimetres in order to raise the center of pressure farther above the center of gravity and give the front wings a greater range of adjustment. Some slight changes were also made in the gearing which drove the pump, so as to make it work faster, and new burners, boilers and a gasoline tank were constructed during November. Later the midrod, which had formerly consisted of two separate pieces attached at the front and rear respectively of the main frame, was made continuous, and in order to avoid passing it through the smoke-stack, the stack was made to fork at this point. These changes are clearly shown in Plates 14 and 15, which are photographs taken on December 3. This plan was, however, soon changed so that the midrod passed through the smoke-stack and was rigidly attached to the frame at several points, and a new pump and new boilers were substituted for those which had been worn out. Aside from these changes, which although small, added very materially to the general strength of the frame, no important changes were made in No. 5 prior to its remarkable flight of May 6, 1896.

While these changes were being made in No. 5, similar ones were also being carried out in New No. 4, and the addition of the rear wings to No. 4, together with other slight changes, made it such a distinctively different machine from what it had been, that it was now designated as No. 6. After making extensive

6a



AERODROME NO. 5, DECEMBER 3, 1895. PLAN VIEW. RUDDER REMOVED



AERODROME NO. 5, DECEMBER 3, 1895. SIDE VIEW

repairs to the extremely light frame of No. 6 (formerly New No. 4) it was thought to be in suitable condition for flight and was accordingly boxed preparatory to sending it to Quantico.

The year, therefore, closed with No. 6 apparently in condition for test, but it was decided not to take it to Quantico until No. 5, which was still undergoing repairs, could also be got ready.

1896

A few days after the beginning of the new year, while the repairs on No. 5 were being completed, it was decided that the frame of No. 6 which had been boxed ready to be carried into the field for trial, was so weak that before putting it to an actual test in flight it would be best to make some tests on the strength of its frame. While testing the frame for torsional strength, it broke under the moderate test of a weight of 500 grammes placed at the tips of the wings, the angle of deflection just prior to its breaking being 35°, while the frame of Old No. 4 in March, 1895, had shown a deflection of only 10.5° under a similar test. This breaking of the frame showed very plainly that the worst fears in regard to it had been realized and that by some means or other the frame must be strengthened. This was finally accomplished by making the midrod continuous through the smoke-stack as had already been done in No. 5, and at the same time an additional improvement was made in the means of attaching the Pénaud tail, whereby it was lowered in order to give it a greater clearance in passing under the launching car in actual test. Later the boilers proved defective and new ones were substituted, but except for some minute details no further changes were made in Aerodrome No. 6 prior to its test in May.

On May 6, No. 6 was unsuccessfully tried at Quantico just prior to the very successful test of No. 5. In this test no serious damage was done to the frame, but before going to Europe in the summer, Mr. Langley ordered that both aerodromes be completely overhauled and put in condition for further experiments in the fall. In this remodelling practically no changes were introduced in the frame of either No. 5 or No. 6, but the engines of No. 6 were refitted and a new boiler was substituted, which, with slight improvements in the burner, resulted in a somewhat increased power in the engines.

A complete description, giving all essential details of both Aerodromes Nos. 5 and 6, will be found in Chapter X.

CHAPTER VIII

HISTORY OF CONSTRUCTION OF SUSTAINING AND GUIDING SURFACES OF AERODROMES 4, 5 AND 6

Introduction

In some early experiments in 1887 with the small models without motor power, which have not been particularly described, two pairs of wings, in the same plane, were employed for reasons connected with stability. Afterward, in many of the rubber-driven motor models, which have been described in Chapter II, two large front wings were employed and the following pair were diminished into what may properly be called a tail. This plan was a retrogression in design, and it was pursued by the writer with a pertinacity which was not justified by the results obtained, being used even on the early rubber-driven models.

In this construction, it will be observed that the flat tail was in fact not only a guiding but a sustaining surface, since it bore its own share of the weight. It was not until a much later date (November, 1895) that the writer returned to his earlier construction of two pairs of wings in the same plane bearing the whole weight of the aerodrome, to which was now added a flat tail, whose function was not to support, but wholly to guide. This was developed into the final construction by the addition of a vertical rudder or rudders.

The present chapter is not concerned with the history of the earlier attempts with small models, or of those numerous constructions of sustaining surfaces which were never put to actual trial; nor does it give any description of the experiments which were made in placing one set of surfaces over the other, according to a method suggested in "Experiments in Aerodynamics."[1]

The experiments in "Aerodynamics," and the theoretical considerations given in Chapter V on sustaining surfaces, would never alone have led to the construction which was finally reached, which was largely due to the hard lessons taught by incessant accident and failure in the field. The present chapter, therefore, should be read in connection not only with the pages of "Aerodynamics," but with Chapters V and IX of this book.

It is to be remembered that, while the center of gravity of the aerodrome could be determined readily and exactly, the center of pressure could be determined only approximately in advance of trial in actual flight. The positions

[1] Chapter V.

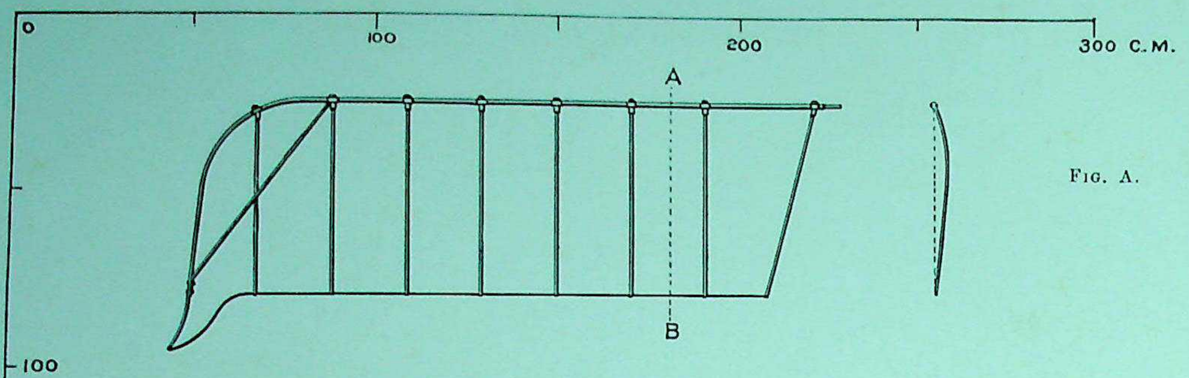


Fig. A.

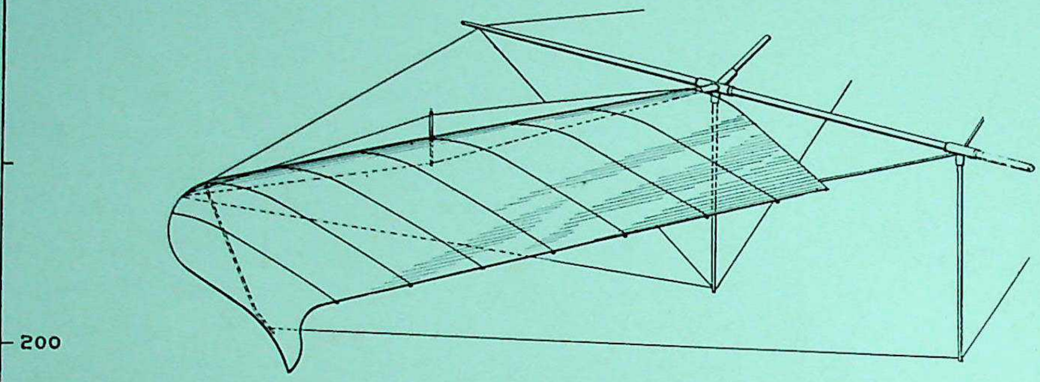


Fig. B.

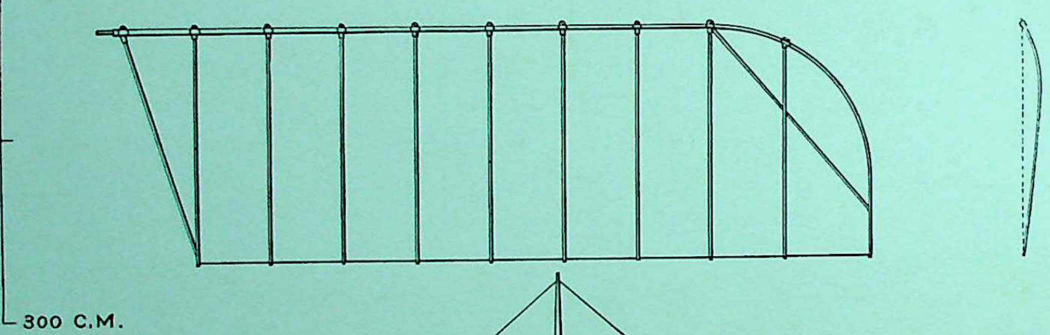


Fig. C.

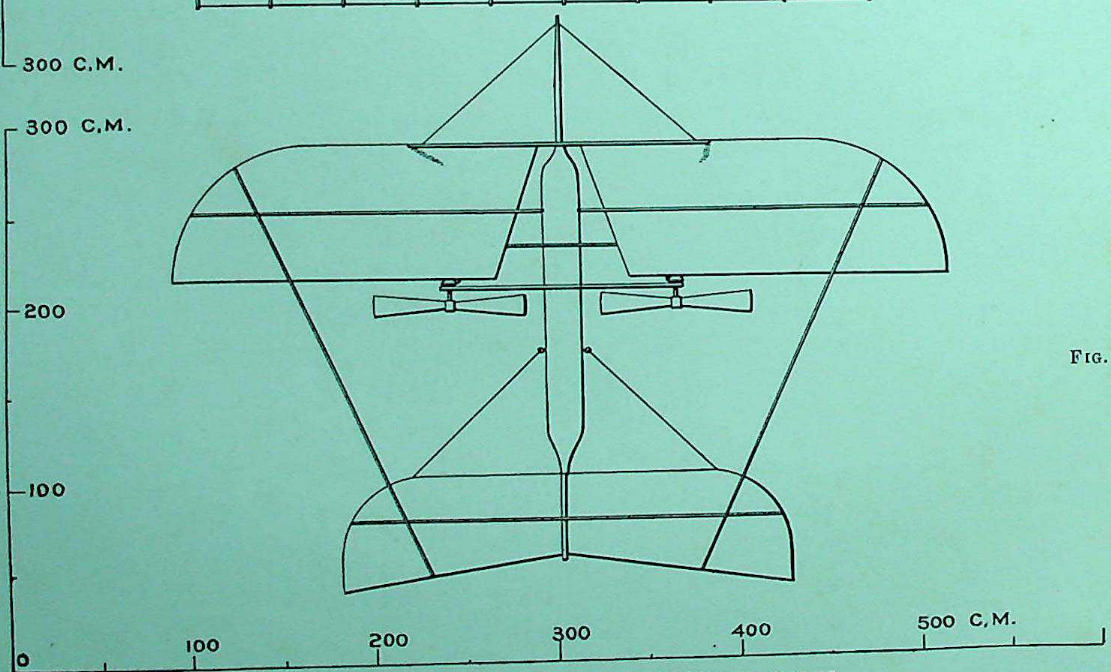


Fig. D.

EARLY TYPES OF WINGS AND SYSTEMS OF GUYING

of the supporting surfaces given in this chapter are, then, approximations made from rules for "balancing," *i. e.*, for obtaining equilibrium in actual flight, rules which are in fact tentative, since they are founded on *a priori* considerations with partial correction from the empirical knowledge gained by previous field trials. For these rules see Chapter VI.

1893

With reference to the supporting and guiding surfaces of Aerodromes Nos. 4, 5, and 6, Aerodrome No. 4, in its earliest condition mentioned in the preceding chapter, was taken into the field, but never brought to trial in the air. It is sufficient to say that in the largest of the three sets of wings constructed, each wing was 17×51 inches, and therefore contained about six square feet, so that with the tail (which was at this time a supporting surface), whose area was one-half that of the two wings, the total supporting surface was 18 square feet, or since the flying weight was 9.1 pounds, the proportion of surface to weight was somewhat less than 2 square feet to the pound. The wings were at this time ribless, it being expected that the silk cover which was purposely left loose would take its curve from the air filling it, which subsequent experience has shown would have led to certain disaster if the aerodrome had been launched. It may be added that there was a vertical rudder of what is now seen to have been a wholly inadequate size. These remarks may be applied with little modification to the attempted flight with No. 4 on May 25, except that the vertical rudder had been made larger, but was still much too small.

1894

From the account of the field trials to be given in Chapter IX, it will be seen that in numerous attempts at flight prior to October 6, 1894, the cause of failure can in every instance be traced to imperfections more fundamental than those of the sustaining surfaces, either the launching device or some other part failing to work satisfactorily. I therefore commence a description of the sustaining surfaces with those of Nos. 4 and 5 as used on that day.

The construction of the wings of No. 4 and No. 5, which were nearly identical, is shown in Fig. *A* Plate 16. A rod of hickory, tapering from ½ inch in diameter at the larger end to ¼ inch at the smaller, was steamed and bent, as shown in the drawing, to form the main front rib of the wing. This was firmly clamped to the midrod, and to the rib in turn were attached a number of cross-ribs of hickory, slightly curved, the inner one of which was fastened to the hull at its inner extremity, while the whole was covered with silk. The length of each wing was 162 cm. (63.75 inches), and the width 54 cm. (21.25 inches). The tail was plane and equal in area to one of the wings, so that the joint area of the wings and tail was 2.62 square metres (28.2 sq. ft.).

Each wing was attached to the midrod by a single clamp, different forms of which are shown at *F, G, H, I* (Fig. 16). The clamp consisted of two short split tubes, into which the main front ribs were securely clamped by means of screws. They were set at an angle and united to a grooved frame, by which the wings could be readily attached to a second piece clamped about the midrod. The tail clamp, like the wing clamp, was composed of two pieces, sliding one upon the other, but as the tail formed a single surface, one part was permanently attached to it. Clamps *F, G* were fitted to aerodrome No. 4, and *H, I* to No. 5. The wings were set at a diedral angle of about 150°, but as they were not guyed in any way, this angle in flight and under the upward pressure of the air probably became much less. The tail was plane but ribbed like the wings.

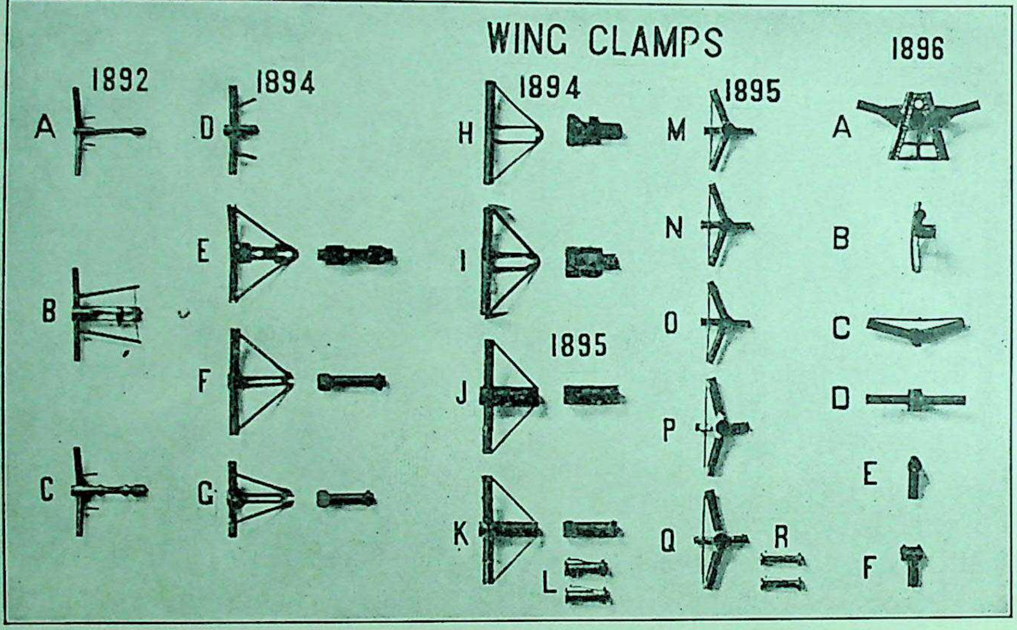


Fig. 16. Wing clamps, 1892-1896.

In preparing the machine for flight, the wings and tail of No. 4 were set at a very small root angle with the midrod, perhaps not exceeding 3°, but while this angle might be maintained at the firmly held root of the wing, it was later seen to be probable that the extremity of the wing was flexed by the upward pressure of the air after launching, though the full extent and evil effect of this flexure was not recognized at the time. In the approximative calculations for "balance," made at this time, the tail was treated as bearing $\frac{1}{3}$ of the weight of the aerodrome, as it was $\frac{1}{3}$ of the supporting area, for though it was recognized that its position in the "lee" of the wings rendered it less efficient, the degree of this diminution of efficiency was not realized. A vertical rudder 20 cm. × 70 cm. (8 in. × 28 in.), with an area of 0.14 metres (1.5 sq. ft.) was used.

The particulars of the launch will be found in Chapter IX. In the present connection, it is sufficient to say that though launched with the requisite velocity and without accident, it fell into the water at a distance of about 15 metres (49 feet) with the midrod nearly horizontal, the combined effect of engines and initial impulse having in fact kept it in the air for less than two seconds. The true cause of this failure not then being recognized, it was attributed to the angle of the wings with the midrod having been too small.

The launch of No. 5 followed almost immediately, but taking warning by the supposed cause of failure of No. 4, its wings were set at a root angle of 20°, and a hurried adjustment was made to secure greater rigidity, the tip being partly secured against twisting by a light cross-piece, and guyed so that the wing as a whole was not only at a greater angle, but stiffer than in the case of No. 4. These changes it was hoped would cause the aerodrome to advance at a considerable initial angle with the horizontal, and it did so, for instantly after the launch, as the aerodrome escaped from its bonds into free air, the inclination of the midrod increased until it stood at about 60°, when the machine, after struggling a moment to maintain itself, slid *backward* into the water (with its engines working at full speed) after advancing about 12 metres (39 feet), and remaining in the air about 3 seconds.

On the whole, the result of the first actual trial of an aerodrome in the field was disconcerting, for unless the result was due to the wings being placed in a position wholly unfavorable to support, there seemed to be no doubt that either the engine power or the supporting surface was insufficient. Now this engine power was by computation between three and four times what was necessary to support the aerodrome in horizontal flight at an angle of 20°, and after making every allowance for slip, there should have been still an excess of power for the first flight of No. 4, whereas actual trial indicated that it was insufficient. But on the other hand, the experiment with No. 5, which momentarily held its position in the air at an angle of 60°, seemed to indicate that the engine power was abundant, and that the failure must be traced to some other cause.

As a result of these experiments it was concluded, "that it is an all-important thing that the angle of the front wing shall be correct, and that this cannot be calculated unless it is known how much the tip will turn up under pressure of the weight." I felt, then, that I had learned something from the failures as to the need of greater rigidity of the wings, though how to obtain this without adding to their weight was a trying problem. It was thus at an early stage suspected that the evil to be guarded against in wing construction was the distortion of the form of the wing under pressure, chiefly by torsion, which is specially hard to provide against without a construction which is nec-

essarily heavy. This suspicion was a correct one, though the full extent of the evil was not yet surmised.

In the light of subsequent experiment it may now be confidently stated that the trouble was with the wings, which at the moment after launching were flexed wholly out of the shape which they were designed to have, and which they retained up to that critical moment.

After returning to Washington, one of the wings was inverted, and a quantity of sand, equal in weight to the pressure upon the wing in flight, was added, under which the yielding at the tip amounted to 65°, or from +20° to −45°, showing that the wings were entirely too weak to sustain the aerodrome.

In speaking of the efforts to strengthen the wings, it must be constantly remembered that this could hardly be done in any way which did not involve increased weight; that is, it could hardly be done at all, since increased weight was forbidden.

The first attempt at systematic guying was made on October 27. As shown in Fig. *B*, Plate 16, two guy-posts extending beneath the midrod were connected by guy-wires with the outer extremities of the wing, by means of which it was sought to hold the wing in place and prevent its extremity from twisting upward, while a third wire connecting with the bowsprit prevented its moving backward. In addition, two aluminum wires, stretched across above from wing to wing, kept the lower guys tight.

On October 27, Aerodrome No. 5, equipped with large new wings and tail, having a combined area of 3.7 square metres (40 sq. ft.), the wings being each 64 cm.×192 cm. (25.25 in.×75.75 in.), turned sharply and completely round, apparently through some internal current of the main wind against which it was advancing. Owing to this almost instantaneous turn, it lost headway and came down. This led to the subsequent construction and use of a much larger vertical rudder, intended to prevent in future any such sudden pivoting and consequent loss of momentum. The wings showed a tendency to "pocket"[2] and bag, which indicated some serious fault in their construction.

As a result of these experiments, it was decided on October 29 to attempt to make the wings stiffer (though their weight was almost prohibitory), by inserting more cross-pieces, cross-pinning and guying them so as to make them more rigid as a whole, and less liable to pocket.

At this time an automatic device in the form of a sliding tail was designed, which it was thought would cause the center of pressure to move backward when the aerodrome reared, and forward when it plunged downward, but the device, though afterward constructed, was never brought to trial in the field.

Aerodrome No. 5, equipped with a new set of wings similar to those used

[2] "Pocketing" is a form of distortion in which the canvas or silk bags locally in numerous places between the cross-ribs.

on October 27, and guyed as in the previous experiment, was again launched on November 21, with the results recorded in Chapter IX. The failure was attributed to the twisting of the wings under pressure to such an extent that not only was their effective area greatly reduced, but the outer portions were upturned so as to catch the air upon the upper surfaces, the result being in part a downward pressure.

On the following day a pair of the wings was inverted and a weight of sand equal to the air pressure to which they were subjected in flight, was distributed over their surfaces. Under the action of this, the twisting of the wing was seen to increase from the root, which was held with comparative rigidity, up to the tip, where in spite of the cross-ribs it amounted to 45°. The resistance to torsion lay chiefly in the front rib, which, in addition, could be bent easily, allowing the surface to become distorted with great loss of lifting power.

The experiments of 1894 had demonstrated the urgent necessity for greater rigidity in the sustaining surfaces, which might, as it seemed, be obtained either by increasing the strength of the framing (which meant additional weight) or by resorting to some new and untried construction, or by a proper system of guying. Guying seemingly offered the most feasible solution of the problem; but although the system of wire guying was thoroughly tried, the result was very unsatisfactory, as the wings continued to twist and bag in a way that was extremely discouraging.

1895

I accordingly had recourse in 1895 to the system of wooden guy-sticks shown in Fig. *D*, Plate 16, which necessarily added greatly to the weight of the sustaining surfaces. Each wing was separately strengthened by means of a light rod of spruce, in cross-section about the size of the main front rib, extending across the upper surface of the wing, at a distance of about one-third the width of the wing behind the front rib. It was tied to each of the cross-ribs and to the outer bent portion of the front rib, and at its root was fastened to the frame of the aerodrome.

This effectually prevented the bending of the front rib and the consequent bagging of the cover, and to that extent marked a decided advance in wing construction. But it was faulty, in that, not being supplemented by wire guying, it offered little resistance to the twisting of the wing about the main front rib, the rear tip of the wing being free to turn up under pressure, as it had done on former occasions. A similar guy-stick was stretched across the tail. To guard against torsion, rods extending diagonally across the wings and tail were used, which, with the aid of the guy-sticks just described, prevented the surfaces from twisting greatly. In addition, a rod joining the front ribs and stretching across from wing to wing tended to maintain a fixed diedral angle.

The wings as thus guyed were rigid enough, and in the field-trials of No. 5 on May 8 and June 6, did not yield noticeably under pressure, and there seemed to be no serious default in their lifting power, but the guy-sticks were heavy and the system was not again employed. The wings used in these trials, shown in Fig. *C*, Plate 16, had a frame of hickory, consisting of a front rib and nine cross-ribs, over which the silk was tightly stretched. The curvature of the wings, which is shown in the cross-sectional drawing, had a rise of about one-twelfth the width, the highest point of curvature occurring about one-fourth the distance from front to rear. Each wing was 64 cm. × 192 cm. (25.25 in. × 75.75 in.), the two with the tail, in surface equal to a single wing, having an area of 3.7 square metres (40 sq. ft.). The combined weight of the wings was 1150 grammes (2.53 pounds), and of the tail, 583 grammes (1.28 pounds).

The evolution of a vertical rudder had meanwhile been going steadily forward. Those first used had been small, rectangular, stiff, and heavy, but in the experiments of May 8 a much lighter and larger construction, consisting of a frame 92 cm. × 76 cm. (36 in. × 30 in.) covered with paper, was used, and on June 7 this was replaced by a long, diamond-shaped rudder, having a spruce frame covered with silk, very light and seemingly more effective than any hitherto used.

I had in the meantime designed a "tail-rudder," consisting of a horizontal tail and vertical rudder combined, each having an area of about 0.6 square metres (6.5 sq. ft.) which, however, was not used until 1896.

In August was begun the construction of a deeply curved and arched pair of wings for No. 4, which consisted of a light framing of spruce elaborately guyed and covered with gold-beater's skin drawn tight as a drum-head with pyroxelene varnish. In their construction a new feature, foreshadowed in the method of guying the separate wings used in the field-trials of May and June, was introduced, which was adopted in all subsequent constructions—the guy-stick, previously described as stretching lengthwise across the wing being now made a part of the wing itself, which was thus provided with two longitudinal ribs instead of one. The additional rib occupied a central position, and like the front rib was attached to the midrod by means of a strong wing clamp. Its outer end was united to the front rib, which was here bent into a quadrant of a circle. This pair of wings had an expanse of 435 cm. (14.3 feet), an area of 2.5 square metres (26.8 sq. ft.), a weight of 660 grammes (1.45 pounds), and a depth of curvature equal to one-tenth their width.

This construction offered a two-fold advantage in its resistance to both torsion and bagging, for as the pressures upon the wing were nearly balanced about the middle rib, the tendency to twist was reduced to a minimum, while the bagging, which results from the bending of the framework, as distinct from

its twisting, was greatly reduced by the manner in which the frame was put together, the whole construction permitting a return to the system of wire guying at first adopted, which had been found inapplicable to a wing having but a single longitudinal rib forming its front margin. When completed, the wings were strongly guyed with piano wire, both above and below, to guy-posts attached to the midrod, and each cross-rib was separately guyed with wire chords. Although these wings had cost much in time and labor, and contained many points of improvement, they were eventually found to be too weak to support the aerodrome, and were therefore abandoned without a trial in the field.

For the plane horizontal tail hitherto used a pair of curved wings was substituted, similar in all respects to those just described, but having only half their area, and these were later replaced by a pair equal in size and in every way the counterpart of the front wings. The tail as hitherto used accordingly disappeared, and gave place to another having a wholly different function to perform; for while the old tail, like the rear pair of wings which superseded it, was intended to bear a definite part of the weight of the aerodrome, the new tail which was now added behind the rear pair of wings was not supposed to bear any part whatever of the weight, but to act solely as a guide, and this new feature, first introduced in October, 1895, was continued to the end.

This arrangement of the surfaces is quite different from that adopted by Pénaud in 1872, in which the tail became automatic in its action through its small angle of elevation as compared with that of the wings, while still acting as a supporting surface, whereas in the present arrangement the function of the tail was solely one of guidance. This, I believe, was one of the important changes which perhaps as much as any other led to final success.

During the fall of 1895 a large number of experiments were made both in free flight with gliding models, and in constrained flight with the whirling-table, to determine the relative lifting power of the front and rear wings per unit of area, and from these the following new rules were deduced for finding the center of pressure:

If a following wing is the size of the leader, assume that its efficiency is 66 per cent per unit of surface.

If it is half the size of the leader, assume that its efficiency is 50 per cent per unit of surface.

If it is half as large again as the leader, assume that its efficiency is 80 per cent per unit of surface.

For intermediate sizes of surface, proportionate values per unit of surface may be assumed.

If we consider the area of the front wing to be unity, and that of the rear wing to be n, and if m be the efficiency of the rear wing per unit of surface,

the above is expressed in the following formulæ, which it will be remembered take account only of wings following each other in the same or nearly the same plane, and are not applicable where one wing is either above or below the plane of the other. In the formulæ, CP is the resultant center of pressure upon both wings expressed in the notation described in Chapter II, CP_{fw} is the center of pressure of the front wings, and CP_{rw} the center of pressure of the rear wings.

If the value of n lie between one-half and unity,

$$m=\frac{n+1}{3};$$

while if the value of n lie between unity and $1\frac{1}{2}$,

$$m=\frac{6+4n}{15}.$$

In either case

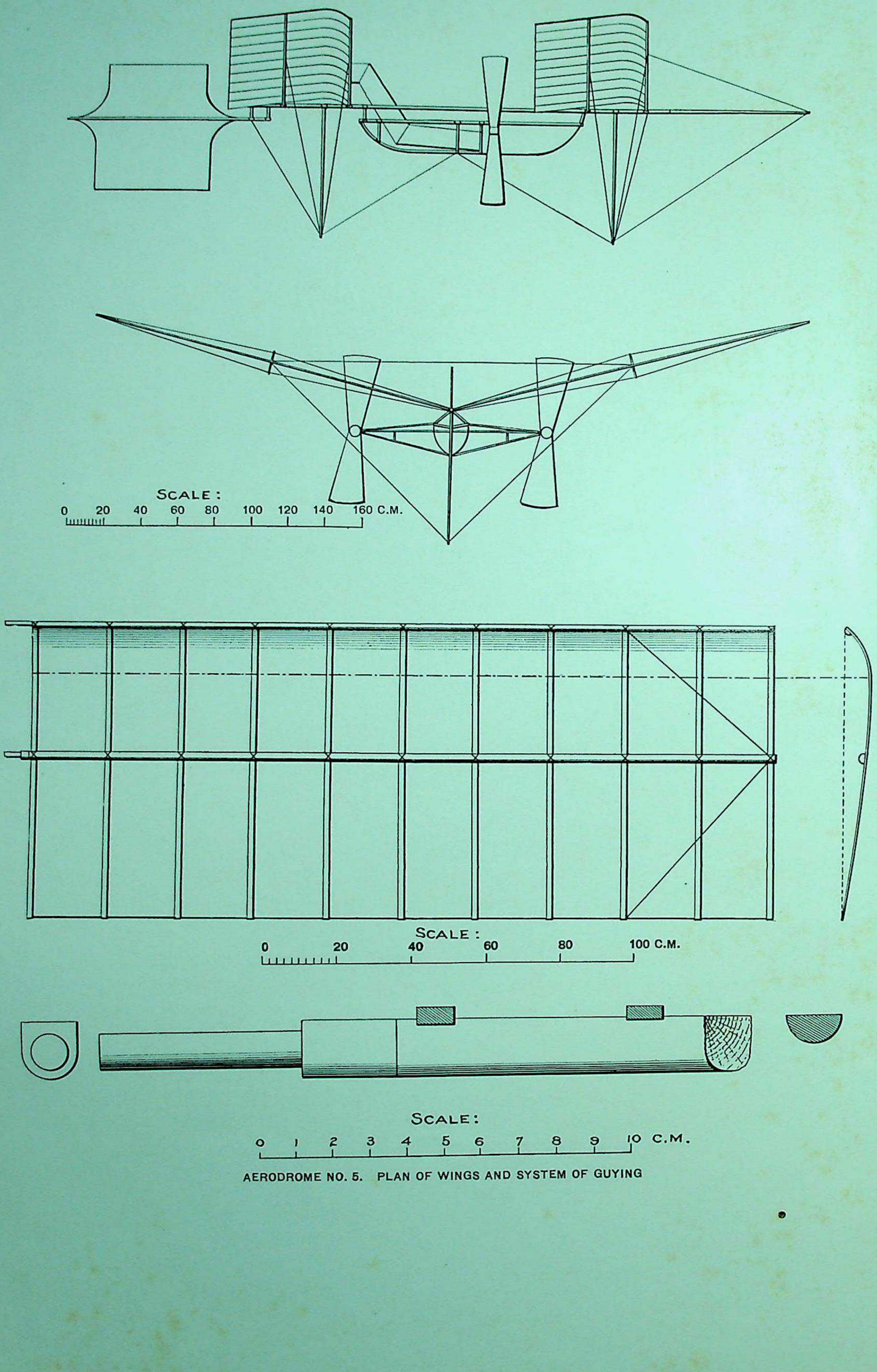
$$CP=\frac{CP_{fw}+mnCP_{rw}}{1+mn};$$

where the leading and following wings are equal

$$n=1,\ m=\tfrac{2}{3} \text{ and } CP=\frac{3CP_{fw}+2CP_{rw}}{5}.$$

The steady flight of one of the gliding models referred to led to the construction of a new set of wings for No. 5, patterned after those used on the gliding model. These wings, shown in Plate 17, were rectangular in outline, 200 cm.×80 cm. (6.56 ft.×2.62 ft.), each wing having an area of 1.6 square metres (17.1 sq. ft.) They were constructed with spruce framing covered with China silk, and were strongly guyed with piano wire in much the same manner as the light, skin-covered wings already described, which had preceded them. The combined weight of the two pair was 1950 grammes (4.3 pounds).

The long central rib was now much the larger of the two which, as in the preceding wing, formed the foundation of the structure. It occupied a position two-fifths the distance from front to rear, and presumably coincided at all points with the center of pressure of fore and aft sections of the wings, so that the pressure in front of the rib was at all points balanced by the pressure in the rear, and there was consequently little tendency in the wing to twist under pressure of the wind. The two main ribs were rigidly connected by cross-ribs of spruce, 20 cm. (8 inches) apart, steamed and bent to the desired form. The curvature of these ribs was the same for all, and in depth was one-twelfth the width of the wing, while the highest point of curvature was one-sixth of the distance from front to rear, these ratios having been chosen as approximating those found in the wing of the soaring bird. These wings were subsequently used in the first successful flights of the following year.



AERODROME NO. 5. PLAN OF WINGS AND SYSTEM OF GUYING

During the year 1895 but two field-trials were made with the steam aerodromes, and neither of these was successful; but a great step forward had been taken in the construction, guying and arrangement of the sustaining surfaces. The wings had been made stronger with no increase in weight per unit of area. On the contrary, the ratio of weight of sustaining surfaces to area had been actually reduced from 43 to 28 grammes per square foot, so that the surfaces were both lighter and stronger.

Two longitudinal ribs had taken the place of the single one before used, a second wing clamp had been added to correspond to the midrib, the difficult problem of torsion had been effectually solved, the system of guying greatly improved, and it appeared that in the next trial the wings might be expected to bear the weight of the aerodrome without serious distortion.

1896

In January, 1896, two new pairs of wings were designed for No. 6, and in order to give a greater efficiency to the rear wings, they were made larger than the front ones, the area of the latter being 22 square feet, and of the former 27 square feet, and whereas the width of each wing had formerly been one-third of its length, it was now increased to two-fifths to correspond to those of No. 5.

The progress made in construction and guying is shown by the fact that when on January 28 one pair of the wings of No. 5 was inverted and sanded, the yielding at the tip was less than 5° greater than at the root, whereas at one time it had been 65°. A similar test applied to a pair of wings of No. 6 on March 4 gave even better results, as the yield at the root was but 1° 45′, and at the tip 2° 30′.

The successive stages of the development of the wing clamps are shown in Fig. 16. In its final form the front wing clamp, or that which held the main front rib, shown at *AB* (1896), had adjustable sliding pieces, by means of which the wings could be set at any desired angle of elevation, the wing as a whole revolving about the rear wing clamp, shown at *CD* (1896).

The general system of guying the wings, as shown in Plate 17, had been greatly improved. In the present form a bowsprit and guy-posts firmly attached to the midrod furnished points of attachment for the piano wires with which the wings were guyed and held rigidly in place, other wires being stretched across from wing to wing so as to maintain them at a constant diedral angle of about 150°. The clamps by which the guy-posts were attached to the midrod, are shown at *EF* (Fig. 16).

In the successful flights of No. 5 on May 6, the completed wings already described weighed together 1950 grammes (4.29 pounds), and had a total sustaining area of 6.4 square metres (68.8 square feet), the flying weight of the aero-

drome was 11,775 grammes (26 pounds), and the sustaining surfaces therefore amounted to 2.6 square feet to the pound, which, as the event proved, was amply sufficient.

The "tail-rudder," shown in Plate 17, comprised a vertical and horizontal surface of silk intersecting in a central rod or axis, having a length of 115 cm. (3.8 feet). The framing was of spruce and consisted of two sets of four arms, each radiating from the central rod, the hexagonal outline of the surfaces being formed of piano wire, over which the silk was drawn and sewed. The area of each surface was about 0.6 square metres (6.45 square feet), and the total weight was 371 grammes (0.8 pounds).

A flat steel spring inserted in the forward end between the rudder and the midrod gave it a certain desirable degree of elasticity in a vertical direction. The rudder was held in place by a pin passing through the midrod, and was so set as to coincide with the line of direct flight, its purpose, as already explained, being to guide the aerodrome, but to take no part in its sustention.

In balancing Aerodrome No. 5 on May 6, the wings were so adjusted that in accordance with the notation given above, p. 15:

$$CP_{fw}=1575$$
$$CP_{rw}=1415.5;$$

and as the wings were of equal size, from what has preceded in the present

$$CP_1=\frac{3CP_{fw}+2CP_{rw}}{5}=1501.2.$$

The center of gravity was located at 1497, so that there should have been a very slight tendency on the part of the aerodrome to rise, as was actually the case. The formula was perhaps not quite so accurate as the prolonged flight of the aerodrome would seem to indicate, as it takes no account of the thrust of the propellers, which in action tended to elevate the aerodrome in front while their resistance would tend to depress it when they had ceased to revolve, which consideration accounts for the action of the aerodrome on May 6, as described in Chapter IX. The formula may, however, be regarded as approximately correct.

In the final successful trial with No. 6 on November 28, 1896, the wings used were similar in general construction and manner of guying to those of No. 5 on May 6, but, as shown in the photograph (Plate 29A, Chapter X), the front rib at its outer extremity was bent to a quadrant to connect with the midrib, this construction being somewhat stronger than that adopted in the wings of No. 5. The curvature was but one-eighteenth of the width of the wing instead of one-twelfth as in No. 5. The front and rear pairs were similar and equal and had a combined area of 5 square metres (54 sq. ft.), and a weight of 2154 grammes (4.74

lbs.). The flying weight of the aerodrome was 12,120 grammes (26.7 lbs.), the sustaining surface thus amounting to slightly more than 2 square feet to the pound.

The position of the wings, in accordance with the notation adopted, was

$$CP_{fw}=1563.2,$$
$$CP_{rw}=1374.$$

Since the wings were equal in size,

$$CP_1=\frac{3CP_{fw}+2CP_{rw}}{5}=1487.5.$$

The center of gravity was located at 1484, which was 3.5 cm. in the rear of the center of pressure. The flight was approximately horizontal, and the setting seems to have been as accurate as could be desired. The angle of elevation of the wings at the root was 10° 30′, and so well were they guyed that there was no visible yielding at any point during the flight. As the midrod during flight was approximately horizontal the angle of elevation of the wings may be taken as 10° 30′; the efficiency of the rear wings was two-thirds that of the front wings, and the effective area was therefore $27+27\times\frac{2}{3}=45$ square feet.

The wings being very nearly plane we have therefore the data for determining the soaring speed from the formula of "Aerodynamics" (Chapter VI, p. 60).

$$W=P_a \cos \alpha = kAV^2F(\alpha) \cos \alpha,$$

in which $W=26.7$ pounds; $A=45$ sq. ft.; $k=0.00166$; $\alpha=10°\ 30'$; $F(\alpha) \cos \alpha=0.353$. By substituting these values in the formula we obtain $V=32$ feet per second.

The speed actually attained, however, was about 30 miles an hour, or 44 feet per second, which seems to indicate that the angle of elevation under pressure was reduced to much less than 10° 30′. For a velocity of 44 feet per second, the theoretical value of α would be but 6°. In this calculation, however, the hull resistance and that of the system of guy-wires, which must have been comparatively large, has been omitted. It would appear, therefore, that the actual results obtainable in flight are much more favorable than calculations based on experimental data would presuppose.

CHAPTER IX

HISTORY OF LAUNCHING APPARATUS AND FIELD-TRIALS OF AERODROMES 4, 5 AND 6

Launching Apparatus

I have elsewhere mentioned that the difficulties of launching even a very small model aerodrome are considerable. Early experiments were tried with an apparatus something like a gigantic cross-bow, and in later years with various forms of pendulum, all of which latter brought out the inherent theoretical defect of the movement of rotation of the aerodrome, and were otherwise practically inefficient.

A device, consisting of two pendulums, one behind the other, connected by a rigid rod, from which the aerodrome could be suspended and cast off without rotation, was at one time considered, but abandoned. Experiments were also made with several forms of railroad, upon which the aerodrome was to run up to the moment of release, before the form of launching apparatus, which finally proved successful, was adopted.

All these had failed chiefly for two reasons; first, it was difficult to cause the aerodrome to be released just at the moment it attained sufficient speed to soar; second, the extensive surface presented to the wind by the wings of the aerodrome, made it necessary to provide means for holding the machine securely at several points up to the moment of release without danger of interfering in any way with the aerodrome when it was cast into the air. This proved a serious problem, which can be appreciated only by one who has seen such a machine in the open air, where its wings are subject to movement and distortion by the slightest breeze. The steps by which these difficulties were removed and the final type of launching apparatus perfected are recorded in the following pages in connection with the field-trials of the model aerodromes.

1892

As the end of the year 1892 approached and with it the completion of an aerodrome of large size which had to be started upon its flight in some way, the method and place of launching it pressed for decision. One thing at least seemed clear. In the present stage of experiment, it was desirable that the aerodrome should—if it must fall—fall into water where it would suffer little injury and be readily recovered, rather than anywhere on land, where it would almost certainly be badly damaged.

The shores of the Potomac on both banks were scrutinized for this purpose, from a point about two miles above Washington to below Chopawamsic Island, some thirty miles below the city. Several lofty and secluded positions were found, but in all these there was the danger that the aerodrome might be wrecked before reaching the water, or, turning in its course, fly inland; but more than this, it could be launched only on the rare occasions when the exact wind was blowing which the local conditions demanded.

Finally, the idea, which seems obvious enough when stated, presented itself of building a kind of house-boat, not to get up initial motion by the boat's own velocity, but to furnish an elevated platform, which could be placed in the midst of a considerable expanse of water, if desired, under conditions which admitted of turning in the direction of the wind, as it need hardly be repeated that it was indispensable to the machine, as it is to the bird, to rise in the face of a wind, if there be any wind at all.

The house-boat in question was nothing more than a scow about 30 feet long by 12 feet wide, upon which a small house was erected, to be used for the occasional storing of the aerodromes. On account of the accidents which were certain to occur in the first attempts, it was fitted up with the means of making small repairs. On the roof of the house there was a platform upon which the operator stood when making a launch, and upon which were mounted the launching devices hereafter described.

This boat, shown in Plate 18, was completed in November, 1892.

1893

By the kindness of the Superintendent of the Coast Survey, the house-boat was towed in May, 1893, down to Chopawamsic Island, a small island near the western bank of the Potomac River, not far from the Quantico station of the Washington and Richmond Railroad Company. A map of the island and the adjacent land and water is shown in Plate 19.

The house-boat was at all times moored somewhere on the west side of the island, in the stretch of quiet water between that and the west shore of the river. The waters shown here are, with the exception of a narrow channel, very shallow, and, indeed, partly dry at low tide, so that there was no danger of an aerodrome being lost, unless its flight carried it a long distance away and over the land.

Field Trials [1]

Aerodrome No. 4, as shown in Plate 11, had a single midrod, a flying weight of 9 pounds,[2] and supporting surface, consisting of wings and tail, of 18 square

[1] The site of these experiments, which was 30 miles below Washington, has been described. The writer is designated by the initial "L"; Dr. Barus, who several times assisted, by the letter "B"; Mr. Reed, carpenter, by "R"; Mr. Maltby, machinist, by "M"; and Mr. Gaertner, instrument maker, by "G."

[2] Weights and dimensions are here given in approximate pounds and feet.

feet. Its engines, with about 100 pounds pressure, developed an aggregate of 0.4 H. P., and lifted 50 per cent of the flying weight. The propellers were 60 cm. (2 feet) in diameter and 1¼ pitch ratio.

The aerodrome was intended to be launched by a contrivance called the "starter," which was an inclined rod, hinged at the bottom, on the top of which the aerodrome was supported on a rod which was thrown down at the instant of flight, giving the aerodrome a slight forward impulse, with the expectation that it would get up sufficient initial speed to soar from the action of its propellers.

On November 18 the writer (L), with Dr. Barus (B) and the two mechanics (R and M), went to Quantico by an early train, and superintended with interested expectation the arrangements for this first trial in the open air of the mechanism which had now been over two years in preparation.

We met with an unexpected difficulty—that of launching the aerodrome at all, for though the wind was only a very gentle breeze, it was only by holding it down with the hands that it was possible to keep the aerodrome in position for the launch, during the few minutes which passed from the time it was placed upon the apparatus to the time of releasing it. Whether the launching device itself might be effective or not could not be ascertained, since it was found that nothing which could even be called an attempt to launch could be made except in an absolute calm; a condition of things very difficult for any one to understand who has not passed through the experience. The writer returned to Washington at the close of the day without having done anything, but having learned a great deal.

November 20. L, with B and M, came down again, and waited until 4.20, when, the breeze having fallen to almost a calm, the aerodrome was maintained in place on the launching apparatus with great difficulty, while it was repeatedly set on fire by the scattering liquid fuel. Finally it was let go, and fell close to the house-boat, the tail striking the edge of the platform. The immediate cause of failure was the defective launching apparatus, for the design of which the writer felt himself responsible.

November 24. L, with B, M, and R came down again to Quantico, but the very moderate wind proved completely prohibitory to any attempt at launching, and all returned again to Washington.

November 27. L, with B and M, came down to try a new launching apparatus, not different in principle from the preceding one, but of better construction. The morning was exceptionally calm, but the engines were found to be out of order, and precious time was spent in slight repairs which should have been made in the shop. At 3.30 p. m., when the engines were at last ready, the exceptional calm gave place to a very gentle and almost imperceptible breeze,

which, nevertheless, again proved prohibitory to the launching, and with extreme disappointment the party returned to Washington, it being at last fully recognized that unless some way were found of holding down all the extended supporting surfaces upon the launching piece, and at the same time of firmly clamping the body of the aerodrome until it could be dropped, as well as of releasing all this simultaneously at the critical instant, no attempt at launching was likely to succeed except in such an entire and perfect calm as rarely occurs. Independent of this launching difficulty, some way of protecting the fires from the wind had to be found, which was by no means easy, since an efficient protection meant an enclosure of them and a diminished influx of air, of which it was essential that there should be an unlimited supply.

December 1. L, with B, R, and M proceeded to Quantico. The same conditions presented themselves and the party returned, without effecting anything.

December 7. L, B, R, and M present; day overcast but perfectly calm. Taught by experience, we had everything ready, and a little after one o'clock the launch was made. The aerodrome fell directly into the boat, the rod of the starter having broken. It was little damaged, but in view of the injury and the rising wind, all other attempts were abandoned for the day.

December 11. Present, L, with B, R, and M. A new "starter" had been devised and brought down, but was not yet quite ready for use, and an attempt was made to employ the old one with the improvements suggested by experience, but, after two attempts to launch, the work was abandoned for the day, owing this time not to the launching apparatus, but to troubles in the engines and pumps, due probably to injuries received in the fall of the 7th, which were not detected until the time of the actual trial.

December 20. L, with B, M, and G, present; engine and aerodrome in order and everything apparently favorable. What seemed to be an almost entire calm came toward evening, yet once more the all but imperceptible breeze which prevailed was found to defeat all arrangements for holding the aerodrome to the launching ways before it was let go.

Trips to Quantico were also made on November 24, and December 1 and 21, of which no account is given as the very moderate wind which prevailed in each case precluded any attempt at launching the aerodrome.

It will be seen that eight trips were made to Quantico, and that, far from any flight having been made, not once even was the aerodrome launched at all. The principal cause for this lay in the unrecognized amount of difficulty introduced by the very smallest wind, irrespective of the unfitness of the launching apparatus to give the desired initial speed and direction.

In all these trials, the aerodrome rested on the launching apparatus, by which it was projected forward by means of a spring in such a way as not to interfere with the propellers.

Previous tests with the rubber-driven models had demonstrated the futility of all simple pendulum types of "cast off," and likewise all the trials hitherto of a railroad form of launching apparatus, in which the aerodrome was mounted on a car, which had itself to get out of the way, were equally failures, so that when the device referred to above proved to be worthless, it seemed that almost every plan had been exhausted. There were, moreover, other difficulties, some of which have been indicated above, such as that of making the burners work properly in even a moderate wind during the very short time required for attaching the wings and so adjusting the aerodrome on the launching apparatus.

These difficulties, which, now that they have been overcome, seem difficulties no longer, but which then seemed insuperable, were all connected with the ever-present problem of weight. It would have been easy to make rigid sustaining surfaces which would not bend in the wind; to make fires which would not go out; and easy to overcome all the impediments which seem so trivial in description and were so formidable in practice, were it not that the mandate of absolute necessity forbade this being done by any contrivance which would add to the weight of an already phenomenally light construction. The difficulties of the flight as they were seen in the workshop were multiplied, then, beyond measure by the actual experiments in the field, and the year closed with a most discouraging outlook.

1894

The new year began without any essential improvement in the means already described, though a new launching apparatus had been devised by the writer, which was scarcely so much an apparatus for launching, in the ordinary sense of the word, as one for holding the aerodrome out over the water, and simply letting it drop from a height of about 25 feet, during which fall it was hoped (exact data being unobtainable in advance of experiment) that there would be time for the propellers to give the aerodrome the necessary soaring speed before reaching the water. This device consisted of an inverted tripod, which held the aerodrome comparatively steady by three bearing points, while a cross-bar of wood was added to prevent the wings from swaying before the launch. Previously, the supporting surfaces, wings and tail, had been put on only at the last minute. Now it became possible to keep them on in a gentle breeze for an indefinite time before launching.

January 9. The previous day having been spent in practicing the steps preliminary to launching, so as to avoid delay in assembling and mounting the aerodrome, the writer, with Dr. Graham Bell, went to Quantico. The day was calm, and every condition seemed favorable. The aerodrome was dropped fairly, under full steam, and it fell in a nearly horizontal position, but touched the water at a distance of only 50 or 60 feet, evidently before the necessary initial speed

could be impressed on it by its engines. The conclusion should have been that by this method nothing but a practically unsuitable height would suffice to start the aerodrome in a calm, though it might perhaps be done in the face of a considerable breeze.

May 25. After a considerable interval of delay, due to the river being closed by ice and other causes, Aerodrome No. 4 was again dropped from the starter under nearly the same conditions as in the trial of January 9, and with a quite similar result, the final conclusion being that this method must be abandoned. It may be added that a vertical rudder was tried on this day.

June 12. No. 4, with an improved blast, was tried at Quantico, Mr. Goode being present. The day ended in failure from another cause, the improved blast, which worked well in the shelter of the shop, but proved useless in the field, being extinguished by the feeblest wind. At this time (in June and July) I designed a horizontal railroad with launching springs and track, underneath which ran a car which held the aerodrome firmly until the moment of automatic release. This apparatus finally proved to be the successful solution of the launching problem. The description given later, with the drawing in Plate 18, shows the after-improvements, but no specific change from that in use from the first.

About this time I also arranged for certain changes in the boilers and burners, having decided that I would not go into the field without some ground for confidence not only that the aerodrome could be launched successfully, but that a steady flame could be maintained under the boilers.

October 6. No. 4, as remodelled, having a flying weight of about 14.5 pounds, a supporting surface of about 28 square feet, with a total engine power of about 0.5 H. P., and having lifted 40 per cent of its weight on the pendulum, was taken down the river for trial with the new railroad launching apparatus, and several days were spent in erecting the launching apparatus on the house-boat, and in launching "dummy" aerodromes from it for practice.

Aerodrome No. 4 then being fitted under conditions which apparently insured a good start (the center of pressure being nearly over the center of gravity, the root angle of the wing being zero, the midrod nearly horizontal, the engine working well, and with apparently ample sustaining surface) was finally successfully launched, but the hopes which were reasonably entertained proved to be unfounded. The result of this first actual trial of a "flying machine" in free air was most disconcerting, for the aerodrome, which had *in theory* many times the power required for horizontal flight, plunged into the water with its engines working at full speed, after a course hardly longer than that performed by the dummy. This result was at first inexplicable.

No. 4, then, did not fly at all, from some at first inscrutable cause, and it was decided to make a trial of No. 5, though it was hard to put the result of so much

time, painstaking and cost to the hazard of destruction. With the experience just acquired from the trial of No. 4, the wing of No. 5 was set at an angle of about 20° with the midrod, and the tip was secured by a light cross-piece, so guyed that the wing as a whole, while set at this considerably greater angle with the rod, was stiffer than before. In addition to this, the air chamber was moved back so that the center of gravity was from 6 to 10 cm. behind the (calculated) center of pressure. These changes were made in order to insure that the front should at any rate keep up, and it did.

The aerodrome was launched successfully with the engines working under a pressure of 110 pounds of steam. The head rose continually until the midrod stood up at an angle of about 60°, checking all further advance. It remained in the air in a stationary position for nearly a second, and then slid *backward* into the water, striking on the end of the rudder and bending it. The distance flown was about 12 metres, and the time of flight 3 seconds. One of the propellers was broken short off, and the shaft was bent.

It thus became clearly evident that some cause prevented the proper balancing of the machine, which was necessary to secure even approximately the theoretically simple condition of horizontal flight. It was all-important that the angle of the front wing should be correct, but its position could not be accurately known in advance of experiment, and this experiment could only be made with the machine itself, and involved the risk of wrecking it.

These trials gave a very vivid object lesson of what had already been anticipated,[3] that the difficulties of actual flight would probably lie even more in obtaining exact balance than in the first and more obvious difficulty of obtaining the mere engine power to sustain a machine in the air. The immediate problem was to account for the totally different behavior of the two aerodromes in the two flights, under not very different conditions.

Observations of the movement of the two aerodromes through the air, as seen by the writer from the shore, seemed to show, however, that the wings did not remain in their original form, but that at the moment of launching there was a sudden flexure and distortion due to the upward pressure of the air. The time of flight was too short, and the speed too great, to be sure of just what did occur, but it seemed probable that the wings flexed under the initial pressure of the weight which came upon them at the moment of launching, and that they were in fact, while in the air, a wholly different thing from what they were an instant before, so that a very slight initial difference in the angle at which they first met the air might cause the air to strike in the one case on the top of the wings and throw the head down, and in the other case so as to throw the head up. To ascertain the extent and character of this flexure, caused, it will be observed, by

[3] "Experiments in Aerodynamics."

the *weight* of the aerodrome suddenly thrown on the wings, I inverted the aerodrome and distributed a weight of dry sand equal to that of the whole machine evenly over the supporting surfaces. It was found that under the weight of the sand the extremity of the wings bent to an angle of 45° downwards (and consequently must have bent to an angle of 45° upwards in the air), a condition of affairs worse than anything that had been suspected, and seeming to demand the entire reconstruction of the wings with a strength and consequent weight for which there was no means of providing.

There had been some injuries to the machines in the trials of the 5th and 6th, and these were repaired. A new float had been made for No. 4, and a new set of larger wings for No. 5. Each of these wings had a length of 76 inches and a breadth of 25 inches, making the total surface of the two 26.4 sq. ft., while that of the tail was 13.2 sq. ft., or about 40 sq. ft. in all.

October 22. When No. 5 was finally prepared for another trial, its condition was as follows:

Flying weight	22 pounds
Area of supporting surfaces (wings and tail).....	40 sq. ft.
Sq. ft. of surface per pound of weight............	1.8 [4]
Engine power with 115 lbs. steam pressure........	1.0 H. P.[5]
Power necessary to soar..........................	0.35 H. P.
Theoretical soaring speed (plane wings at 20°)....	24 ft. per sec.
Previous lift on pendulum.......................	40 per cent of flying weight

October 25. The aerodromes having been taken to Quantico on October 23, and satisfactory experiments made with dummies in order to test the launching apparatus, the house-boat was carried out into midstream and moored.

Aerodrome No. 4 was launched in the face of a wind of about 1100 feet per minute. The midrod was at a very small inclination with the horizontal, about 3°. The angle (α) of the chord of the curved wing measured at the rod, where it was rigidly held, was 15°. The adjustment was such as to bring the *CG* immediately under the *CP*, without any allowance for the fact that the line of propeller thrust was below the *CP*.[6] The aerodrome under these conditions was launched with the head high. It made a real, though brief, flight of about 130 feet in 4½ seconds, when it swung abruptly round through 90°, and, losing headway, sank continuously, finally falling backward into the water.

October 27. Aerodrome No. 4, having been repaired and guyed with wires from the wings to vertical guy-posts beneath, was launched again, but one of the

[4] On the data of "Aerodynamics," a plane having 1.8 sq. ft. of surface per pound, and advancing at an angle of 20°, would soar at a speed of 24.1 ft. per second.

[5] It will be remembered that the purely theoretical conclusions just cited apply to the power delivered in direct thrust, but that of the above actual H. P. an indefinite amount was lost in friction and slip of propellers.

[6] It may be observed that at this time the position of the *CP* was calculated on the assumption that the pressure for flight surfaces was proportional to the areas, without also allowing for the fact that the following surfaces, like the tail, were under the "lee" of the wind and so far less efficient. It follows, then, that the value *CP* — *CG* was not really 0, as was assumed, but something considerable.

guy-wires caught on the launching car, and threw the aerodrome immediately into the water with but little damage.

On the same day No. 5 was launched. The theoretical $CP-CG$ was nominally 0, but, for the reasons stated in the footnote on p. 99, was really something positive, that is to say, the CP was really somewhat in advance of the CG; inclination of midrod less than α ($=20°$). The aerodrome under these circumstances, while keeping its head up, at first fell rapidly, yet seemed about to rise just as it struck the water, conveying the idea that if the launching had been made with a greater initial velocity it would have risen and cleared the water. The wings visibly pocketed, however, and it was clear that some better disposition must still be made for them. The flight was $3\frac{1}{2}$ seconds.

No. 5 was tried again on the same day with larger wings, whose area was 40 square feet. These wings, though stiffer, pocketed a little. $\alpha=20°$ as before. It flew rapidly, and at first horizontally, to a distance of 100 feet or more against a five-mile breeze. It then turned abruptly round through 180°, at first falling (from loss of headway), then distinctly rising, and at the same time throwing its head up until it reached an angle of nearly 60° with the vertical, when it fell backward after a flight of between 6 and 7 seconds. The wings were evidently not yet strong enough to resist flexure.

November 21. No. 5, in nearly the same condition as before. Two extra springs had been placed on the launching car, in order to give the aerodrome a greater initial velocity than before. Everything appeared favorable, but as it left the launching track a piece flew out of the port propeller, in spite of which the aerodrome, after dropping 5 feet, rose bodily at an angle of 45° and fell backward into the water (time, 5 seconds).

Another trial was made the same day with the same aerodrome, under similar conditions, except that the angle of inclination (α) was reduced to 7°. It now, with all the other circumstances of launching like those immediately before, behaved entirely differently, plunging head downward into the water at a distance of 30 feet. Once more it was shown beyond dispute that the wings must somehow be made even stiffer.

December 8. Another trial was undertaken with No. 5, the CG being 10 cm. in front of the CP at rest. The root angle of the wings was 18°, tip angle 27°, elevation of midrod 1 in 24. The other changes made since the previous trial consisted chiefly in the increased weight due to the longer and stronger frames and shafts that were made to carry 100 cm. propellers. The flight obtained was so short that it was as unsatisfactory as before.

The aerodrome rose in the air after leaving the launching apparatus, and then slid back into the water in the plane of its own wings. On the first trial, it struck the boat, and was slightly injured; on the second, with root angle of

wings 10°, tip angle 20°, the flight partook of the same character, but the machine struck the water clear of the boat.

The fact that with the *CG* 10 cm. in advance of the calculated *CP* the aerodrome steadily rose in front, seems to indicate that the rule used at that time for calculating the *CP* (see Chapter II) was not very accurate. This rule was based upon the assumption that the tail, having an area equal to one-third the entire sustaining surface, supported one-third the total weight (expressed by the formula $CP = \frac{2CP_{wm} + CP_{tm}}{3}$, where CP_{wm} and CP_{tm} represent respectively the *CP* of the wings and tail in motion), and that the *CP* of each surface was one-fifth its width in front of the center of figure.

December 12. Four days later, the tail had been moved back 21 cm., thus carrying the *CG* back 7 cm., but the vertical rudder (weighing 105 grammes), for which there was now no room, was taken off, which in a measure counteracted this change.

A trial was then made with the wings set at an initial angle of 8° at the root and 20° at the tip. The aerodrome was released with the engines working under a steam pressure of 90 pounds, and soared off horizontally for some distance, when suddenly it swerved to the right as though something on that side had given out, and turning quite through 180° headed toward the boat, striking the water about 76 feet away. The time of the flight was 4 seconds.

It was found upon the recovery of the machine that one of the propellers had been twisted through 90°, so that the two were no longer symmetrical. The turning may have been due to this twist or to unequal influence of the wind upon the two wings; for when I applied the sand test to the wings after returning them to Washington, it was found that they deflected so much that the grains would not lie upon them, which, to a great extent, explains the failure to secure a better flight.

Thus the end of another year had been reached, and what might be called a real flight had not yet been secured. The only progress that seemed to have been made was that the aerodromes were not quite so unmanageable and erratic in their flights as at the beginning of the year, and that it had been demonstrated, at least to the writer's satisfaction, that the power was sufficient for the work to be done. The launching device had been so perfected that it worked satisfactorily, but the problem of balancing seemed as far from solution as before.

1895

While, for convenience in narrating the progress of the work with the aerodromes, each year has been treated as a unit, it is, of course, understood that the work itself shows no especial difference between the closing of one year and the beginning of another. Changes which had important effects were introduced

at various times, but were, of course, made as they suggested themselves without any reference to time or season. But while it was customary to make, from time to time, a résumé of the progress of the work, yet at the closing of the calendar year it was the custom to make a more complete digest of just what had been accomplished during the year.

Upon thus reviewing the progress of the work during 1894, it was felt that the results which had been accomplished for such a large expenditure of time seemed small, since no real flight had been made by any of the aerodromes, and no definite assurance that a successful flight would be obtained within the immediate future seemed warranted by what had already been accomplished. But now that the principal difficulties connected with the launching apparatus had been overcome, thus permitting the aerodromes themselves to be given a fair trial, the belief was encouraged that the continuance of the actual tests of the machines, with slight changes which previous tests had shown advisable, would finally result in a successful flight.

The early weeks of 1895 were spent in a series of pendulum tests on No. 5, and in making such slight changes as these tests indicated would be advisable. As a result of small improvements introduced in the boilers, No. 5 had by the middle of March shown a repeated lift of considerably over 50 per cent, and in some tests as much as 62 per cent of its flying weight. Certain radical changes previously described in Chapter VII were also made in Aerodrome No. 4, and in the pendulum tests of it a lift of 44 per cent of its flying weight had been obtained.

Encouraged by the better results which the aerodromes had shown in the above tests, it was decided to test them again in free flight, and they were accordingly sent down to Quantico in charge of the two mechanics, R and M, Mr. Langley, accompanied by Dr. Graham Bell, whom he had invited to witness the tests, following on May 8. On the evening of May 8 No. 5 was mounted on the launching apparatus in order to drill the mechanics so that when favorable weather presented itself the aerodrome could be got ready for launching with the minimum delay.

On May 9 Mr. Langley and Dr. Bell reached the house-boat at 5 a. m., but even with the drill of the previous evening the mechanics were not able to have No. 5 ready for trial until 6.15 a. m. The principal conditions of No. 5 at this time were:

Total weight 11,200 grammes (24.6 pounds), including 800 grammes of fuel and water. Previous lift on the pendulum 54 per cent, with a steam pressure of 150 pounds. With this steam pressure the engine made about 600 R. P. M. when driving the 95 cm. propellers, which through their reduction gearing made about 500 R. P. M.

When the aerodrome was balanced for flight so as to bring the theoretical "center of pressure in motion" over the center of gravity, it was found that it was not possible to carry the center of gravity in front of this point, although it was known by experience to be necessary. Accordingly in the first trial the outer ends of the tail were pressed down by the guys so that the wind of advance tended to lift the tail and throw the head down more than if the tail had been flat. Furthermore, the float, weighing 200 grammes, instead of being placed in its normal position near the base of the bowsprit, was carried out to its extremity, this change in the position of the float alone being sufficient to carry the center of gravity forward three or four centimetres. The curved wings were set at an angle of nine degrees at the root and eleven degrees at the tip. They were well guyed, and in flight appeared to be not materially twisted or altered.

It was anticipated that the pressing down of the outer ends of the tail and the shifting of the center of gravity would cause the aerodrome to point downward in flight, and this anticipation was verified in the test. At 6.15 a. m. the aerodrome was launched at a steam pressure of 120 pounds. A perfect calm prevailed at the time and the machine started straight ahead. There was no perceptible drop at the moment it was released from the launching car, but a smooth and steady descent until it struck the water, nose down, at a point approximately 200 feet from the boat. Dr. Bell noted that the length of time the aerodrome was in the air was 2.8 seconds. One of the propellers was broken and the other one was found to have twisted its shaft one-fourth of a turn.

At 9.45 a. m., the wings having been dried, No. 5 was again tried. The float was moved back to its normal position at the base of the bowsprit, and the guys, by which the outer ends of the tail had been depressed in the previous trial, were so adjusted that the tail was flat. The machine was, therefore, in the condition of theoretical equilibrium for rapid motion with a plane wing. All the other conditions were precisely as in the previous trial, except that the round-end 100-centimetre propellers were substituted for the 95-centimetre ones which had been broken, and a new paper-covered tail was used. The mechanic in charge was directed to let the steam reach its highest pressure consistent with a flight of one-half a minute, before launching the machine, but he seemed to have lost all sense of the length of time the fuel and water would last, as he let the engines run until almost the whole charge was exhausted before launching it. The aerodrome went off almost horizontally, then turned up into the wind and rose to an angle of about twenty degrees; then (while moving forward) slowly sank as though the engine power had given out, as in fact it doubtless had. The actual distance travelled was 123 feet and the length of time 7.2 seconds. While the exhaustion of the fuel and water prior to launching the machine had prevented what apparently would otherwise have been an exceed-

ingly good flight, yet the fact that the aerodrome rose immediately after being launched, and continued to do so until the power gave out, was in itself very encouraging.

At 1.40 p. m. No. 5 was again ready for trial (the third one for the day), and this time Mr. Langley and Dr. Bell witnessed it from a greater distance in hopes of being able more clearly to study its behavior when actually in the air.

The previous trial having missed success through the fuel and water having been consumed before the machine was launched, special instructions were given to avoid the recurrence of this mistake. But the machine was held for probably two minutes after the burners were lighted, with very much the same result as before. The conditions of the aerodrome were the same as in the previous trial, except that the tail was a little flatter, so as to tend to make the head slightly lower in flight. It was launched at an angle of about thirty degrees with the very gentle wind that was blowing, and, apparently under the direction of the rudder, turned into the wind, the midrod rising to an angle of about twenty degrees and (as noted in Mr. Langley's record book) "The whole machine absolutely rising during five or six seconds—a fine spectacle! Then the power visibly gave out, the propellers revolving slower. It settled forward and lost nearly all of its forward motion at the end of about seven seconds, but did not finally touch the water until ten and a quarter seconds."

While the length of time that the aerodrome had been sustained in the air was so short that no actual flight had really been achieved, yet the results encouraged the belief that with the aerodrome more accurately balanced, it could reasonably be hoped that a somewhat longer flight would be obtained. It was, however, very evident that, although the correct balancing which would insure equilibrium for a few minutes might soon be attained, the machine, lacking a human intelligence to control it, must be provided with some mechanism which would tend to restore the equilibrium, the conditions of which must necessarily change in a machine depending on the air for its support. In order to see what could be done in this direction, it was, therefore, decided to return immediately to Washington with the machines and make some minor changes in them before attempting further flights.

By the end of May, Nos. 4 and 5 were again in readiness for a trial, and the mechanics were accordingly sent to Quantico to complete preparations for the tests. During May Mr. A. M. Herring, who had been experimenting with model machines for several years, was engaged for a few months as an assistant, and he was immediately put in charge of the field trials of Nos. 4 and 5, which were now about to be made. On June 6 Mr. Langley, accompanied by Mr. Herring, went to Quantico, and on June 7, at 5 a. m., Aerodrome No. 5 was ready for trial, but the wind was so high that nothing could be done. The wind later diminished in intensity, but the house-boat had become stuck on the beach

and it was impossible to make the launching apparatus point directly into the wind, which was blowing from the rear of the boat. An attempt was made to launch the aerodrome even with the wind blowing at its rear, but it was found impossible to make the fires burn and the test was accordingly postponed. Later in the afternoon the house-boat was floated and the preparations for a test were immediately completed. At 5.42 p. m. the fires were lighted, but the burners did not work properly and the proper steam pressure could not be obtained. At 6.20 p. m. the fires were again lighted, and at 6.22 the aerodrome was launched, its midrod having an upward angle of 25 degrees, or more, with the launching track. The aerodrome moved off nearly horizontally, but seemed to be very sluggish in its movement and fell in the water about seventy feet from the boat, after having been in the air only 4.8 seconds. The damage consisted of a broken propeller and a slight strain in the main frame, the extent of which, however, was not immediately seen.

The steam pressure at the time of launching was 110 pounds, which was obviously insufficient. The aerodrome had lifted fifty per cent of its weight on the pendulum, and its sluggishness of movement seemed, therefore, unaccountable even for this pressure. It seemed probable, however, that the pressure ran down immediately after the machine was launched, on account either of the use of the light-weight burners in place of the larger and heavier ones, or of the diminution of the air pressure in the gas tank.

At 7.55 the aerodrome was again launched, and this time made a still shorter flight than before, being in the air only three seconds. A serious leak in the engine cylinder was, however, discovered just as the machine was launched, and this probably accounted for the lack of power.

Not only had the tests which have just been described indicated that there was a lack of power during flight, although previous pendulum tests had repeatedly shown lifts greater than fifty per cent, but, furthermore, the wings themselves, while appearing perfectly capable of supporting the aerodrome when viewed with the machine stationary, were seen to flex to such an extent in flight that it seemed probable that much of the power was consumed in merely overcoming the head resistance of a large portion of the wings which had lost all lifting effect.

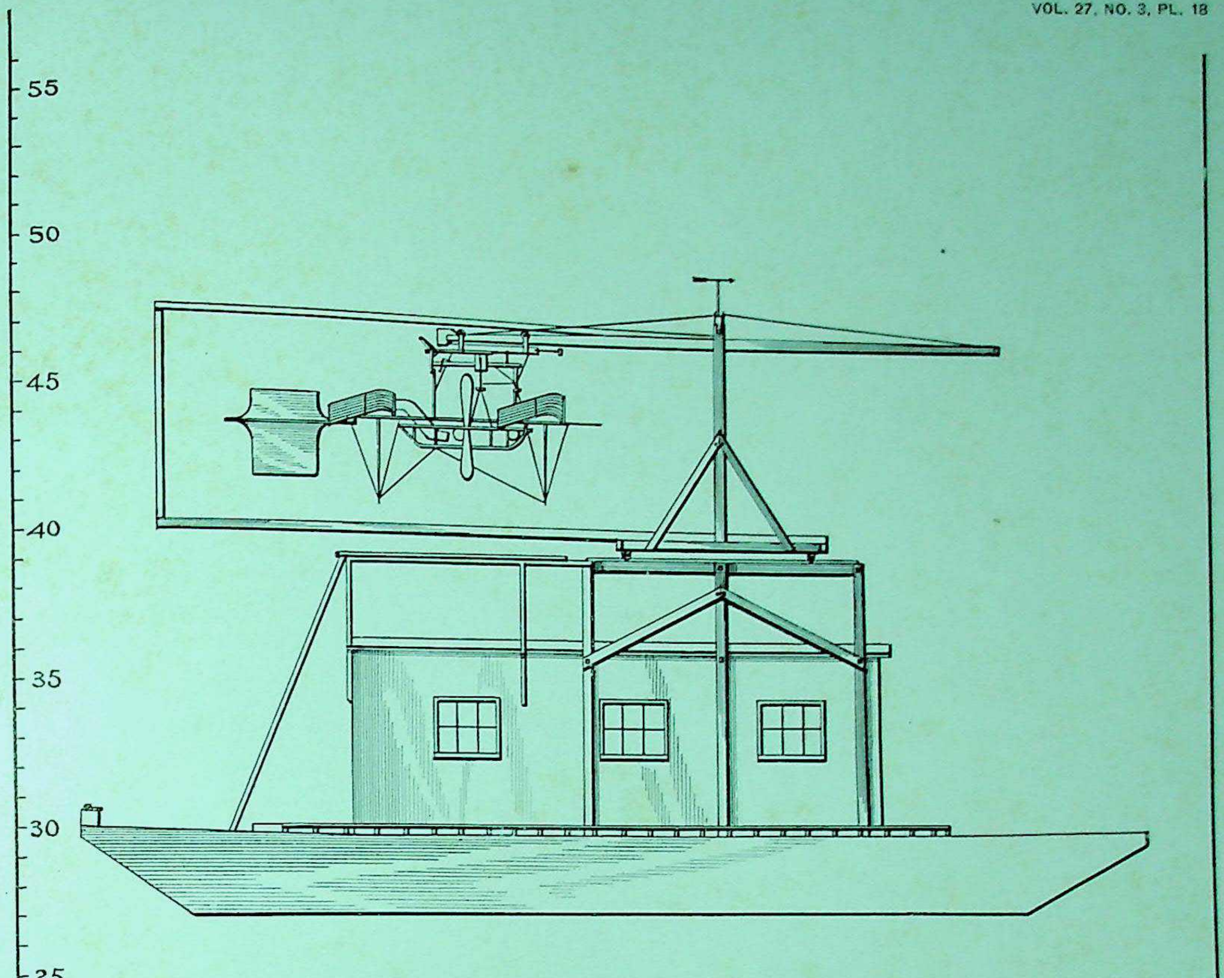
During the fall and winter, as recorded in Chapters VII and VIII, Aerodrome "New No. 4," which had been reconstructed during the summer, and which upon test was found radically weak, was almost entirely rebuilt and afterwards known as No. 6. Important changes were also made in No. 5, which greatly increased its strength and power. The improvements, however, which contributed more than anything else to the marked success achieved in the next trial of the aerodromes, were those which had to do with the nature and disposition of the sustaining surfaces and the means for securing equilibrium.

It will be recalled that in the more recent trials the apparent causes of failure had been the inability to provide sufficiently rigid wings, the great difficulty of properly adjusting the relative positions of the centers of pressure and gravity, and the lack of any means of regaining equilibrium when the balance of the aerodrome had in any way been disturbed. In the fall of 1895, accordingly, it was finally decided to employ a second pair of wings equal in size to the first or leading pair. This not only added greatly to the stability of the aerodrome, but also made it possible, without any alteration in the plan of the frame, to bring the center of pressure into the proper position relative to the center of gravity. In addition the plan of constructing the wings was modified by the introduction of a second main rib, which, placed at approximately the center of pressure of the wings, made them much stiffer, both against bending and torsion. The two pairs of wings now became the sole means of support, and the tail which had hitherto been made to bear part of the weight of the aerodrome, as well as assist in preserving the longitudinal equilibrium, was now intended to perform only the latter function. It was placed in the rear of the wings and was combined with the vertical rudder. Further, in adjusting it on the aerodrome, it was set at a small negative angle and given a certain degree of elasticity, as described above. This device proved to be a most efficient means of maintaining and restoring the equilibrium, when it was disturbed, and its value was apparent in all future tests of the models.

1896

The important changes in the steam-driven models which had been begun in the previous fall, and which in the case of No. 4 had been so extensive as to convert it into a new aerodrome, No. 6, were continued during the early spring, and it was not until the last of April that the models Nos. 5 and 6 were ready for actual test in free flight.

The condition of No. 5, which made the first successful flight, is given in the data sheet for May 6, 1896, and its general form at this time may be seen in the photograph of May 11, Plate 27A. Although the changes described above, as well as the modifications in the boilers and burners of both aerodromes had undoubtedly effected a great improvement in every detail of the machines, the disappointments experienced in the preceding years prevented any great feeling of confidence that the trials which were now to be made would be entirely successful. On May 4, however, the two mechanics, Mr. Reed and Mr. Maltby, were sent down to Quantico with Aerodromes Nos. 5 and 6, and Mr. Langley, accompanied by Dr. Graham Bell, who had been invited to witness the tests, followed on the afternoon of the 5th. On May 6 the wind was so very high all the morning that a test was found impracticable. During the forenoon, however, the wind gradually died down, and by 1 p. m. was blowing from six to ten miles an



HOUSE-BOAT WITH OVERHEAD LAUNCHING APPARATUS, 1896

hour from the northeast. At 1.10 p. m. Aerodrome No. 6 was launched, but the guy-wire uniting the wings having apparently caught on one of the fixed wooden strips which held the wings down, the left wing was broken before the aerodrome was really launched, and the result was that the machine slowly settled down in the water by the boat, breaking the propellers and slightly injuring the Pénaud tail.

After removing No. 6 from the water, No. 5 was placed on the launching car and immediately prepared for a test. At 3.05 p. m. it was launched at a steam pressure of 150 pounds and started directly ahead into the gentle breeze which was then blowing. The height of the launching track above the water was about twenty feet. Immediately after leaving the launching track, the aerodrome slowly descended three or four feet, but immediately began to rise, its midrod pointing upward at an increasing angle until it made about ten degrees with the horizon and then remained remarkably constant at this angle through the flight. Shortly after leaving the launching track the aerodrome began to circle to the right and moved around with great steadiness, traversing a spiral path, as shown in the diagram (Plate 19). From an inspection of the diagram, it will be noticed that the aerodrome made two complete turns and started on the third one. During the first two turns the machine was constantly and steadily ascending, and at the end of the second turn it had reached a height variously estimated by the different observers at from 70 to 100 feet. When at this height, and after the lapse of one minute and twenty seconds, the propellers were seen to be moving perceptibly slower and the machine began to descend slowly, at the same time moving forward and changing the angle of inclination of the midrod until the bow pointed slightly downward. It finally touched the water to the south of the house-boat at the position shown, the time the machine was in the air having been one minute and thirty seconds from the moment of launching. The distance actually traversed, as estimated by plotting its curved path on the coast-survey chart and then measuring this path, was approximately 3300 feet, which is the mean of three independent estimates. This estimate of the distance was checked by noting the number of revolutions of the propellers as recorded by the revolution counter, which was set in motion at the moment the machine was launched. On the assumption that the slip of the propellers was not greater than fifty per cent, the 1166 revolutions as shown by the counter would indicate a distance travelled of 2430 feet. As it was felt very certain that the slip of the propellers could not have amounted to as much as fifty per cent, it seemed a conservative estimate to place the length of flight at 3000 feet, which would mean a rate of travel of between 20 and 25 miles an hour. The circular path traversed by the aerodrome was accounted for by the fact that the guy-wires on one of the wings had not been tightened up properly, thus causing a difference in the lifting effect of the two sides.

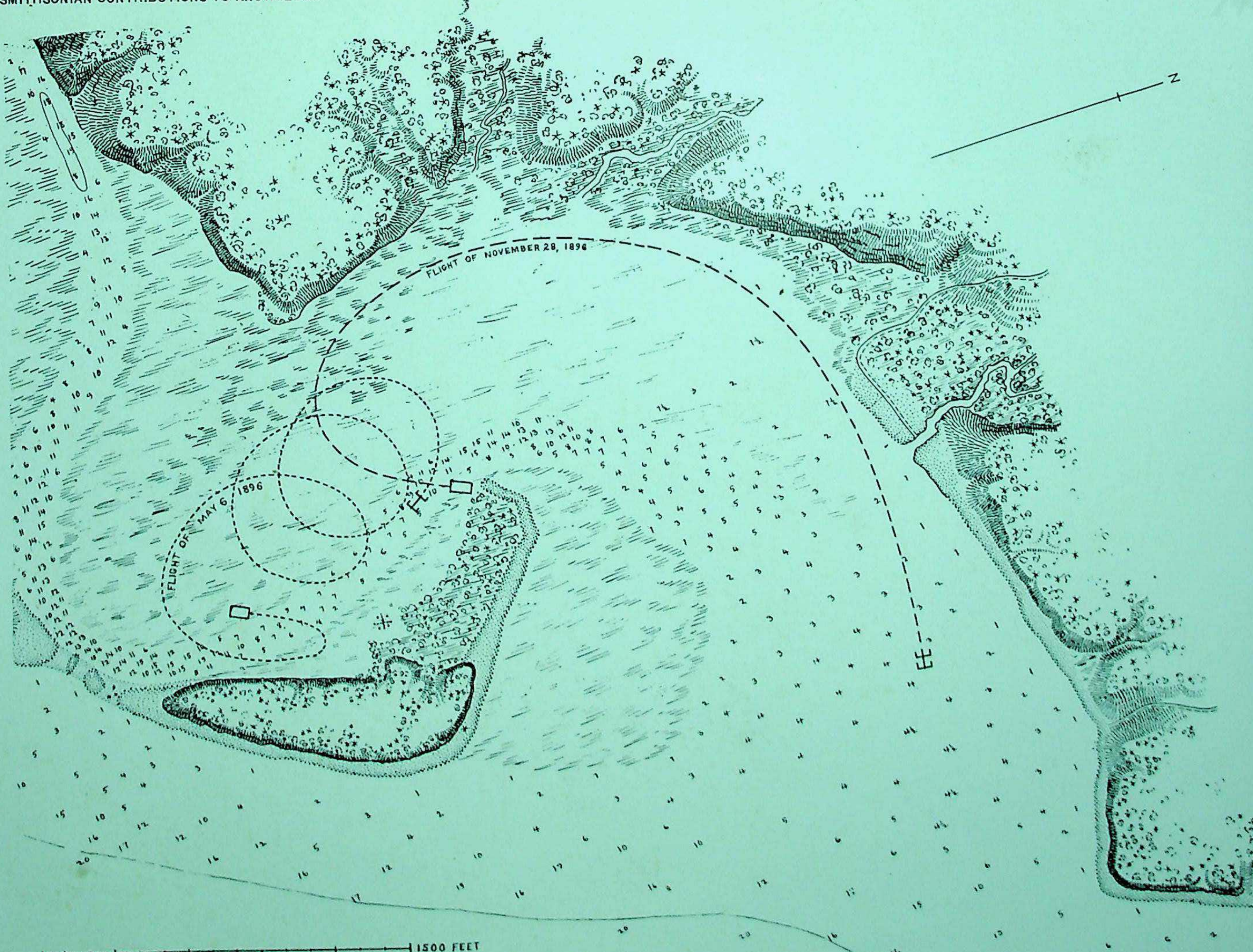
The aerodrome was immediately recovered from the water and preparations made for a second test, the machine being launched again at 5.10 p. m. at a steam pressure of 160 pounds. The conditions were the same as at the first trial, except that the wind had changed from north to south and was perhaps of less velocity than before. The path traversed by the aerodrome in this second trial was almost a duplicate of the previous one, except that on account of the change in the direction of the wind the machine was launched in the opposite direction. In tightening up the guy-wires, which had not been properly adjusted in the previous test, they were probably tightened somewhat too much, since in this second test the aerodrome circled towards the left, whereas in the first flight it had circled towards the right. The aerodrome made three complete turns, rising to a height of approximately sixty feet with its midrod inclined to the horizon at a slightly greater angle than before. The propellers again ceased turning while the machine was high in the air and it glided forward and downward and finally settled on the water after having been in the air one minute and thirty-one seconds. The distance travelled was estimated as before, by plotting the path on the coast-survey chart, and was found to be 2300 feet.

During these flights several photographs were secured of the machine while it was actually in the air, some of the pictures being taken by Dr. Bell and others by Mr. F. E. Fowle. The clearest of these are shown in Plates 20, 21, and 22.

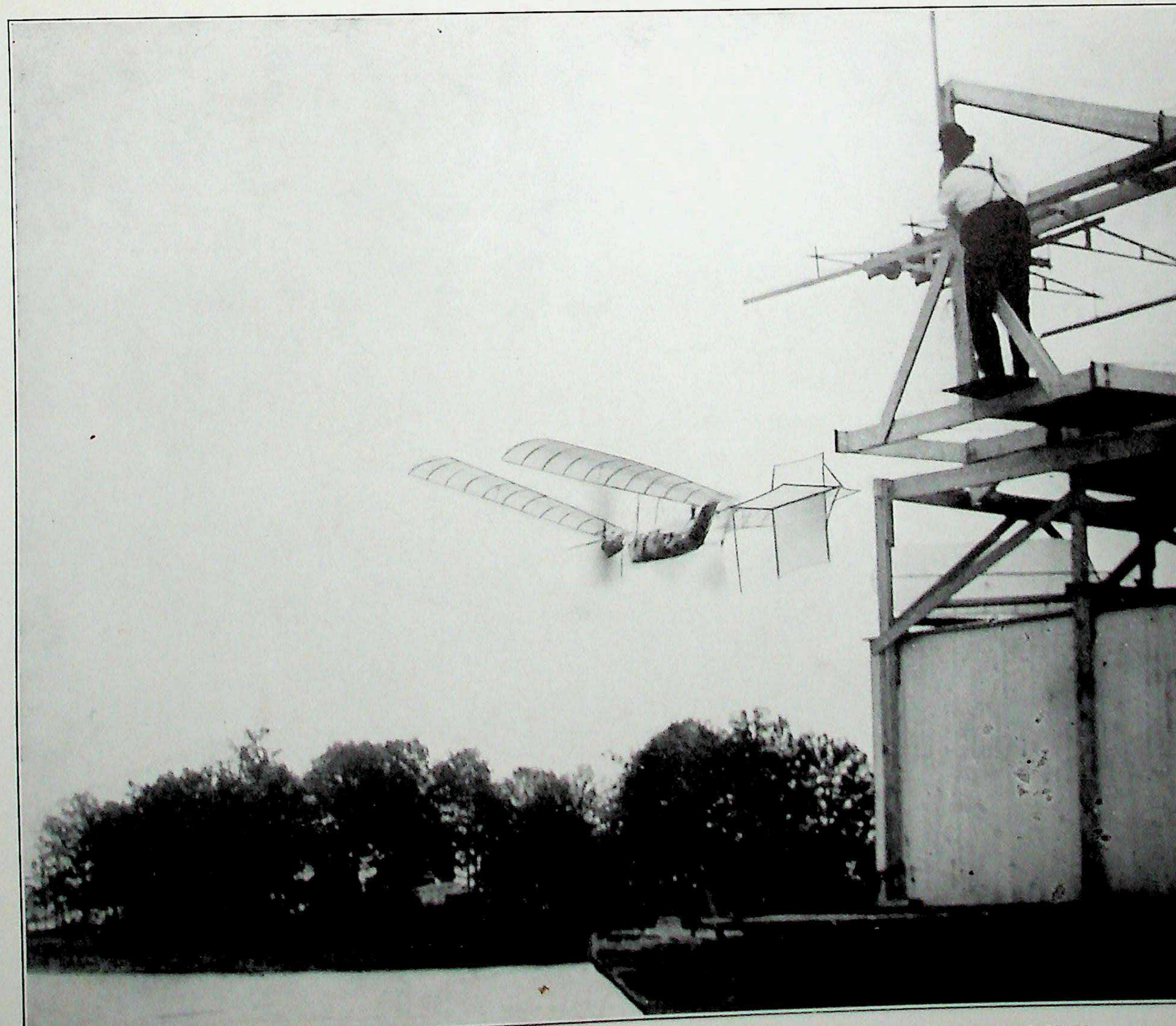
Just what these flights meant to Mr. Langley can be readily understood. They meant success! For the first time in the history of the world a device produced by man had actually flown through the air, and had preserved its equilibrium without the aid of a guiding human intelligence. Not only had this device flown, but it had been given a second trial and had again flown and had demonstrated that the result obtained in the first test was no mere accident.

Shortly after returning to Washington, Mr. Langley left for Europe, but before doing so he gave instructions to the workmen to remedy the small weaknesses and defects which had been found in Aerodrome No. 6, and to have both aerodromes ready for trial before his return in the fall.

After returning in the fall, Mr. Langley again had Aerodromes Nos. 5 and 6 taken down to Quantico for trial, and this time had as his invited guest Mr. Frank G. Carpenter. On November 27 a test was made of Aerodrome No. 6, the general disposition of which at this time may be learned from the description in Chapter X, and the photographs in Plates 29A, 29B. The model was launched at 4.25 p. m. with a steam pressure of 125 pounds. The aerodrome went nearly horizontally against the wind, and descended into the water in six and a quarter seconds at a distance of perhaps 100 yards. After the machine had been recovered from the water, it was found that a pin had broken in the synchronizing rod which connects the two propeller shafts together, and that the counter, which showed 495 revolutions of the propellers, had been caused to register inaccu-

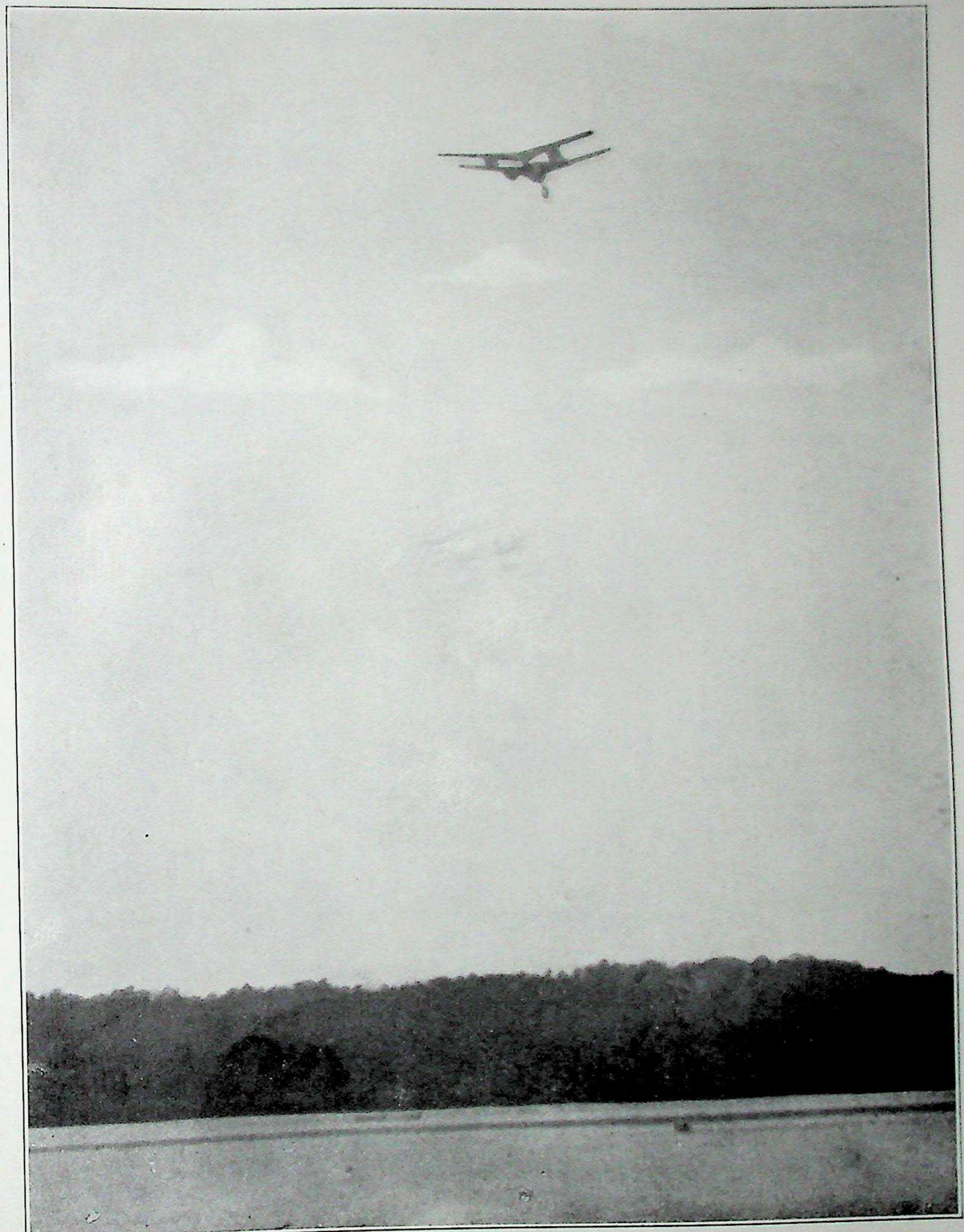


PATH OF AERODROME FLIGHTS, MAY 6 AND NOVEMBER 28, 1896, NEAR QUANTICO, VA., ON THE POTOMAC RIVER

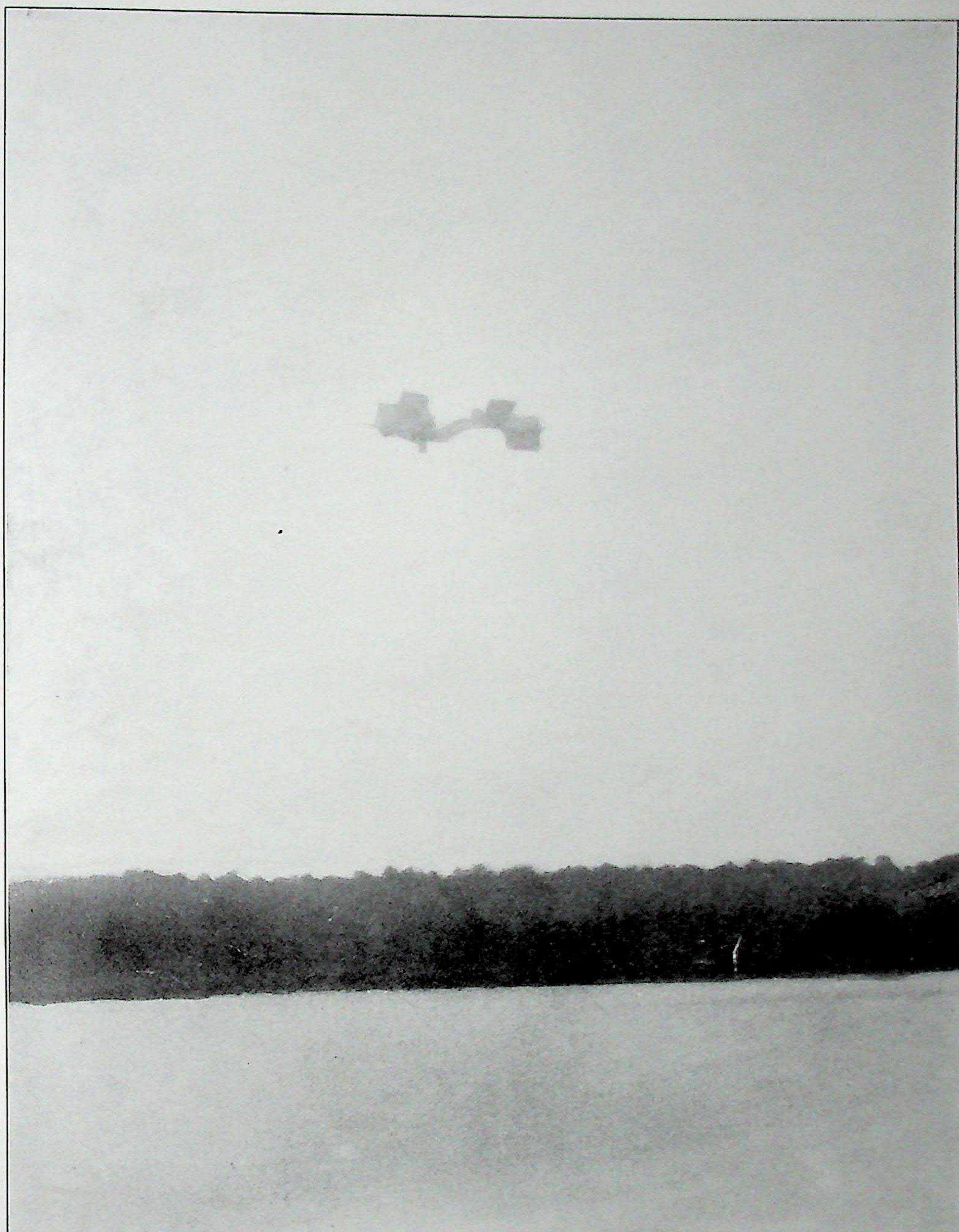


INSTANTANEOUS PHOTOGRAPH OF THE AERODROME AT THE MOMENT AFTER LAUNCHING IN ITS FLIGHT AT QUANTICO ON THE POTOMAC RIVER, MAY 6, 1896. ENLARGED TEN TIMES

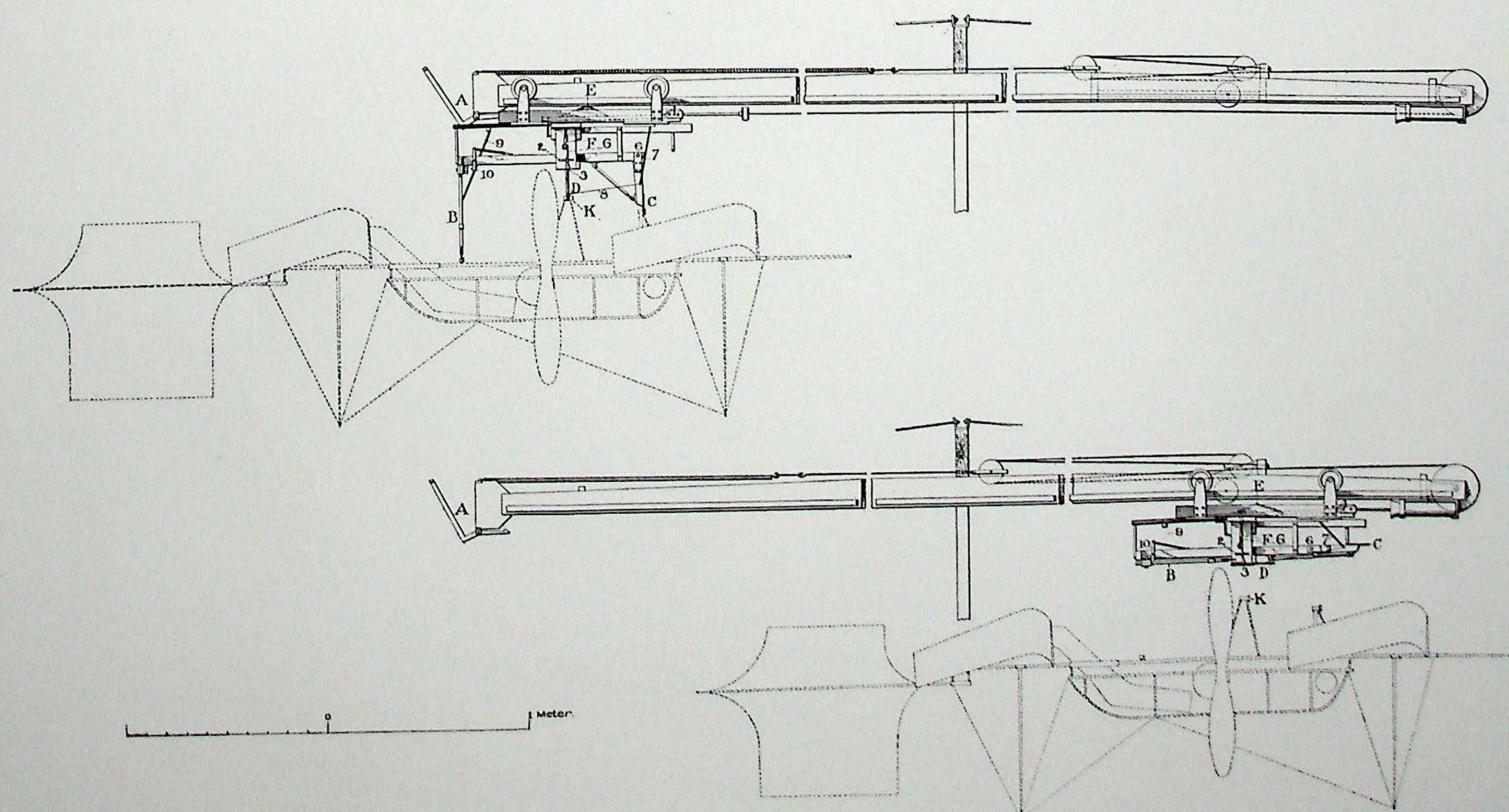
9a



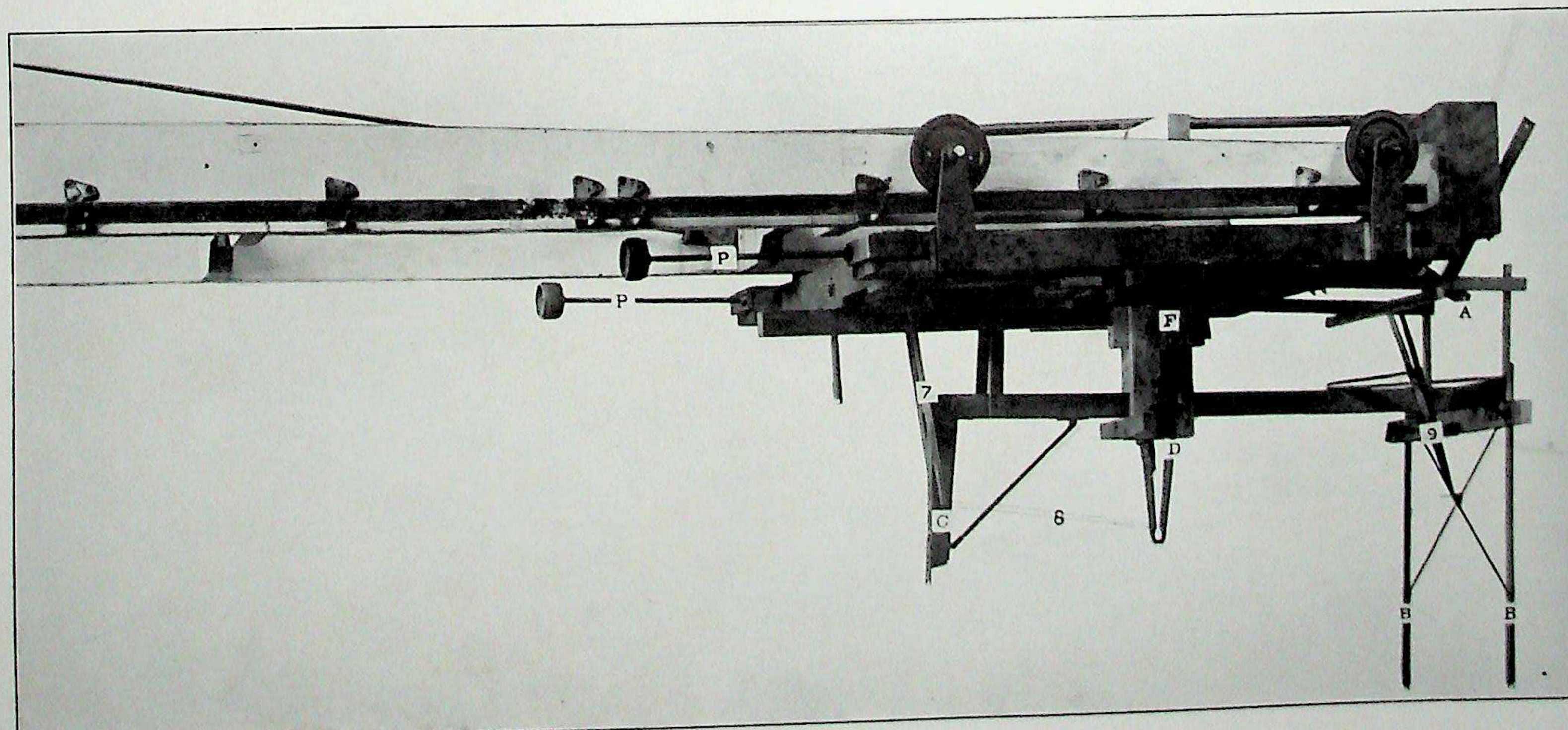
INSTANTANEOUS PHOTOGRAPH OF THE AERODROME AT A DISTANCE IN THE AIR DURING ITS FLIGHT AT QUANTICO ON THE POTOMAC RIVER, MAY 6, 1896. ENLARGED TEN TIMES



INSTANTANEOUS PHOTOGRAPH OF THE AERODROME AT A DISTANCE IN THE AIR DURING ITS FLIGHT AT QUANTICO ON THE POTOMAC RIVER, MAY 6, 1896. ENLARGED TEN TIMES



OVERHEAD LAUNCHING APPARATUS



OVERHEAD LAUNCHING APPARATUS

rately on this account. The balancing of Aerodrome No. 6 had been made the same as that of No. 5, but in No. 6 the line of thrust was twelve centimetres higher, and this fact, which had not been taken into account in determining the proper balancing for No. 6, seemed to be sufficient cause for the aerodrome coming down into the water so soon after being launched. Darkness had descended before the aerodrome could be recovered and prepared for a second trial. On the next day, November 28, a high wind prevailed in the morning, but in the afternoon it became comparatively calm, and No. 6 was launched at 4.20 p. m. under the same conditions as on the preceding day, except that the float, which weighed 275 grammes, was moved back from the bowsprit eighty centimetres in order to make the machine lighter in front. The aerodrome was launched at a steam pressure of not much over 100 pounds, the air draft for the burners being temporarily bad. The midrod made an angle of approximately three degrees with the horizontal. On account of a slight rain, which had occurred just before the machine was launched, the wings were wet and the weight of the entire aerodrome was doubtless as much as twelve kilos. Immediately on being launched the aerodrome started directly ahead in a gentle south wind, moving horizontally and slowly turning to the right and appearing to approach dangerously near to some thick woods on the west shore. However, it fortunately continued turning until it pointed directly up the beach with the wind in the rear. It then moved more rapidly forward, dipped and rose but once, and this very slightly, and continued its remarkable horizontal flight, varying not more than two yards out of a horizontal course, and this only for a moment, until it finally descended into the bay at a point nearly in a line between the house-boat and the railroad station at Quantico. Upon being recovered, it was found to be absolutely uninjured, and another flight would have been made with it immediately but darkness had descended. The time of flight, as determined independently by two stop-watches, was one minute and forty-five seconds. The number of revolutions of the propellers was 2801, or at the rate of 1600 R. P. M., which, with an allowance of fifty per cent slip, should have carried the aerodrome a distance of 4600 feet in one and three-quarter minutes. While the distance from the house-boat in a straight line to the point at which the aerodrome descended was only about 1600 feet, yet it was estimated by those present that this straight-line distance was certainly not greater than one-third the total length of the path traversed, which would mean a distance of something like 4800 feet. The length of the course, as plotted on the coast-survey map and afterwards measured, was 4200 feet, and it, therefore, seemed safe to say that the total distance travelled was about three-quarters of a mile, and the speed was, therefore, about thirty miles an hour.

CHAPTER X

DESCRIPTION OF THE LAUNCHING APPARATUS AND OF AERODROMES Nos. 5 AND 6

Reference has already been made to the development of the "cast-off" apparatus that was used at Quantico for launching the aerodrome. An initial velocity is indispensable, and after long experiment with other forms which proved failures, an apparatus was designed by me, which gave a sufficient linear velocity in any direction. It had, moreover, been found that, when the aerodrome was attached to any apparatus upon the roof of the house-boat, such slight changes in the direction and intensity of the wind as would ordinarily pass unperceived, would tend to distort or loosen it from its support, so that only the most rigid of fastenings at three independent bearing points were of any use in holding it, while the wings must be separately fastened down, lest they should be torn from their sockets. It was, then, necessary to be able to fasten the aerodrome very firmly to the cast-off apparatus, to start it upon its journey in any direction with an initial linear velocity that should equal its soaring speed, and to release it simultaneously at all points at the very same instant, while at the same time the points of contact of the launching device, to which it had just been fastened, were themselves drawn up out of the way of the passing propellers and guys.

All these requirements and others were met by the apparatus finally adopted, which is shown in Plates 23 and 24. It consists of a strong timber frame-work, carrying a track, consisting of two flat iron rails set on edge, upon which runs the launching car, suspended from two small wheels on each side. At the front end of the frame there are two cylindrical air buffers to receive the buffing pistons and thus stop the car after the aerodrome has been released. The car is drawn to the rear end of the track and held by the bell-crank lever *A* (Plate 23). The contact points *BB* and *C* are turned down and the clutch-hook *D* set over the clutch-post *K*. The aerodrome is thus held firmly up against the three points *BB* and *C* by the clutch *D*, and a distortion from its proper position rendered impossible. All these points are thrown up out of the way of the projecting portions of the aerodrome at the instant of release. This result is accomplished as follows: when the car has reached the proper point in its forward course, the cam *E*, which is hinged at 1, is depressed by a roller fixed to the framework of the device. In this motion it pushes down the adjustable connections *FF*, which are attached at their lower ends to the bell-crank arms *GG*, which turn about a central pivot at 2. Thus the downward movement of the connections *FF* opens the jaws of the

clutch *D*. While the clutch *D* is rigidly attached to *G* to prevent transverse movement, it is hinged to the latter at 3 so that it can fold in a longitudinal direction. Screwed to the clutch *D* is a narrow plate 4, which, when the clutch is closed, is behind the lug 5, thus preventing any turning about the hinge 3.

But when the arms of *G* and the jaws of the clamp are thrown out by the depression of *F*, the plate 4 is moved out from behind the lug 5 and the clamp is free to fold to the front. The strut, hinged at 6, is under a constant tension from the spring 7 to fold up, and is prevented from doing so only by the connections 8, by which it is held down until the release of the plate 4 from behind the lug 5, when the spring snaps them instantly up and out of the way.

As the struts *BB* have no fixed connection with the aerodrome, they are released by the relaxation in the rigidity of the other connections and are thrown up by their spring 9 and held in that position by the clip 10 catching beneath the upper cross-piece.

The power for the propulsion of the car is obtained by means of from one to nine helical springs working under tension, and multiplying their own motion four times by means of a movable two-sheave pulley, as shown in the drawing.

Description of Aerodrome No. 5

When the details of the aerodrome, whose description is to follow, are considered from the standpoint of the engineer accustomed to make every provision against breakage and accident and to allow an ample factor of safety in every part, they will be found far too weak to stand the stresses that were put upon them. But it must be remembered that in designing this machine, all precedent had to be laid aside and new rules, adapted to the new conditions, applied. It was absolutely necessary, in order to insure success, that the weight should be cut down to the lowest possible point, and when this was reached it was found that the factor of safety had been almost entirely done away with. and that the stresses applied and the strength of material were almost equal.

The same observation holds true of the boilers, aeolipile, and engines, when regarded from the point of view of the economical generation and use of steam. It was fully recognized that the waste of heat in the coil boilers was excessive, but as it was necessary that there should be an exceedingly rapid generation of steam with a small heating surface, this was regarded as inevitable.

In the engine the three points aimed at in the design were lightness, strength and power, but lightness above all, and necessarily in a degree which long seemed incompatible with strength. No attempt was made to secure the requirements of modern steam-engine construction, either in the distribution of the steam or the protection of the cylinder against the radiation of heat by a suitable jacketing. The very narrow limits of weight permissible required that the bar-

rel of the cylinder should be as thin as possible, that no protective jacketing should be used, and that the valve motion should be of the simplest description. To obtaining the greatest lightness consistent with indispensable power, everything else was subordinated; and hence, all expectation of ordinary economical efficiency had to be abandoned at the outset.

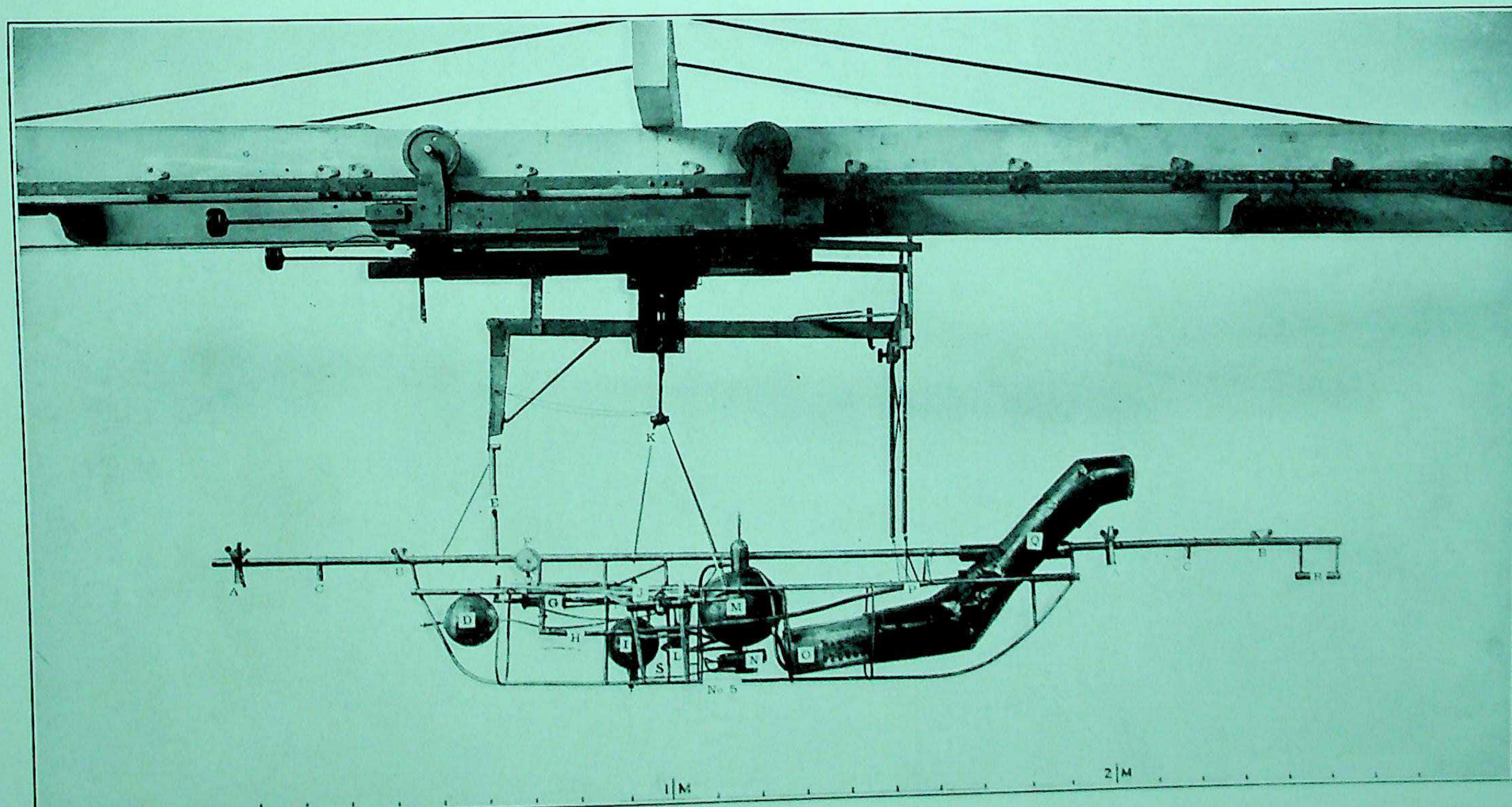
It was only after long trials in other directions that Mr. Langley introduced the aeolipile device, which for the first time provided sufficient heat. Even in the aeolipile, however, it was apparent that nothing short of the most complete combustion accompanied by the highest possible temperature of the flame would be sufficient for the extreme demand. To secure this result under all conditions of wind and weather, with the aerodrome at rest and in motion, required the long series of experiments that are given in another chapter. In respect to the generation of heat, then, it is probable that it would be difficult to exceed the performance of the final type of burner in practical work, but in the utilization of this heat in the boiler, as well as in the utilization of the steam there generated, the waste was so great as to be prohibitive under ordinary conditions. But this was not ordinary work, and the simplest protection against radiation from boiler, separator, and engine could not well be used.

The framework of the aerodrome is made of thin steel tubes, the main or midrod extending the whole length of the machine and carrying the attachments to which the wings are fastened. Suspended from this midrod by rigid connections is a skeleton hull of steel tubing, shaped somewhat like the framework of a boat, from which, directly abeam of the engines, arms are run out like the outriggers of a rowboat for carrying the propellers. Within this central hull are placed the aeolipile, the boiler, and the engine, which with their auxiliary parts, the pump and the separator, constitute the entire power-generating apparatus.

The aeolipile consists of four essential parts: the spherical air chamber containing the supply of compressed air by which the gasoline in the reservoir tank is forced into the burner; the reservoir tank containing the gasoline that is to be used as a fuel; the gas generator wherein the liquid gasoline is heated and converted into gas; and the burners where it is finally utilized to heat the boilers.

The air chamber *D,* Plate 25, is a spherical vessel 120 mm. in diameter, located at the extreme front end of the hull. It is made of copper 0.25 mm. thick and has two openings. The front opening has a copper pipe 1 cm. outside diameter, to which the air pump for charging the chamber is connected. From the back a copper pipe 5 mm. outside diameter extends to the top of the gasoline reservoir.

This reservoir, shown at *I,* Plate 25, is also a light, hollow sphere 120 mm. in diameter; both this and the air chamber being made by soldering hemispheres



SIDEVIEW OF STEEL FRAME OF AERODROME NO. 5 SUSPENDED FROM LAUNCHING-CAR, OCTOBER 24, 1896

of copper together at their circumferences. There are three openings in the reservoir tank; two at the top and one at the bottom. One of those at the top serves for the admission of the 5-mm. pipe bringing compressed air from the air chamber; the other is connected with a pipe 1 cm. in diameter, through which gasoline is supplied to the tank, and which is closed by a simple plug at the top. The hole in the bottom serves as the outlet for the gasoline to the burners. Close to the bottom of the tank there is placed a small needle valve, which serves to regulate the flow of oil, for, were the pipe left open, the compressed air would force the oil out with such rapidity that the burners would be flooded and the intensity of the flame impaired. The construction of this valve is clearly shown in Plate 26A. It consists of a brass shell having one end (*a*) soldered to the bottom of the tank. The needle enters through a stuffing box whose gland is held by two small screws. The stem of the needle is threaded and engages in a thread cut in the body of the casting and is operated by a fine wire on the outside. It will readily be seen that this device affords a means of making a very accurate adjustment of the flow of the liquid to the burners.

After leaving the needle valve the gasoline flows along the pipe *S*, Plate 25, until it reaches the evaporating coil, *N*. In order to subject the oil to as large a heating surface as possible, in comparison with the sectional area through which it is flowing, the pipe, which left the needle valve with a diameter of 6 mm. soon contracted to 5 mm., is here flattened to a width of 7 mm. and a thickness of 2 mm. There are seven complete turns of this flattened tubing coiled to an outside diameter of 30 mm. At the end of the seventh coil the pipe is enlarged to a diameter of 1 cm. and two coils of this size are added, the inside diameter being the same as that of the flattened coil. This enlarged portion serves as a sort of expansion chamber for the complete gasification of the gasoline, which is then led back through a turn of the enlarged pipe, beneath the coils and to the front. At the front end of the coil a small branch is led off, forming a "bleeder," which takes sufficient gas to supply the burner by which the coil is heated, the products of whose combustion pass into and between the coils of the boiler like those of the regular heating burners. The gas pipe rises in front of the coil and by a *T* connection branches to the two burners that are placed in front of the coils of the boiler. These burner pipes are 5 mm. in diameter and enter sheet-iron hoods forming regular burners of the Bunsen type, which are fully shown in all their details in the accompanying engraving, Plate 26. The pipe is plugged at the end, and a hole 0.9 mm. in diameter drilled for the nipple of the burner in front of the coil where the water first enters from the separator, and 0.85 mm. for the one in front of the return coil. The face of the burner shell stands exactly central with and 41 mm. in front of the coils.[1]

[1] Very exact accuracy in these minute details is indispensable to the efficient working of the engines.

This constitutes the heat-generating portion of the machine, and with it it is probable that a flame of as high a temperature is produced as can be reached, with the fuel used, by any practical device.

The boiler or steam-generating apparatus may be said to consist of three parts: the separator, the circulating pumps, and the generating coils.

The separator (*M* in Plate 25) is a device which has attained its present form after a long course of development. As at present constructed, it is formed of a hollow sphere 190 mm. in diameter and is located as nearly as possible over the center of gravity of the whole apparatus. It serves the double purpose of water reservoir and steam drum, and is called a "separator" on account of the function which it performs of separating the water from the steam as it enters from the coils. There is a straight vertical pipe 10 mm. in diameter rising from the top of the sphere and fastened to the right-hand side of the midrod. This is used for filling the separator with water. Upon the other side of the midrod there is a small steam dome 42 mm. in diameter with a semi-spherical top rising to a height of 70 mm. above the top of the sphere. From this dome two steam pipes are led off, one to the engine and the other to the steam gauge.

As already stated elsewhere, it was found in the experiments with the coil boiler that an artificial forcing of the circulation of the water was a necessity, as the natural circulation was too slow to be of any service. Accordingly, but only after numerous devices involving less weight had failed, a pump driven from the engine shaft was designed and used. In the early experiments various types of pumps were tried in which the valves were opened and closed automatically by the pressure of the water. It was found, however, that with the mixture of steam and water to be handled, the valves could not be depended upon to open and close properly at the high speeds at which it was necessary to run the engine. In Aerodrome No. 5, therefore, a double-acting pump with a mechanically operated valve was used. The pump, shown in detail in Plate 26A, is driven from a shaft connected with the main engine shaft by a spur gear and pinion, which rotates at half the speed of the engine shaft. The pump itself consists of two barrels, the main barrel having a diameter of 23 mm. with a piston stroke of 20 mm. The outer shell of the barrel is made of aluminum bronze and is lined with a cast-iron bushing 1.25 mm. in thickness. The piston has a length of 14 mm. and is formed of an aluminum disc and center, having a follower plate of the same material with two cast-iron split rings sprung in. The water is received into and delivered from the valve cylinder, which is 18 mm. in diameter and also lined with a cast-iron bushing 1.25 mm. thick. The aluminum bronze shells of both cylinders are 0.75 mm. in thickness. The valve is a simple piston valve 35 mm. long with bearing faces 4 mm. long at each end. The water is taken from the bottom of the separator and led to the center of the valve chest of the pump by a copper p pe 1 cm. outside diameter. The ports

leading from the valve to the main cylinder are 3 mm. wide and 34 mm. apart over their openings. It will thus be seen that when the valve is in its central position, as it should be at the beginning of the piston stroke, both ports are covered with a lap of 0.5 mm. inside and out, so that the valve has to move 0.5 mm. before suction or discharge can take place. As the valve is moving most rapidly at this point, it opens and both functions begin before the piston has advanced perceptibly. The delivery is made at the ends of the valve cylinder through two copper pipes of 1 cm. diameter that unite into a single pipe before reaching the boiler. The throw of the valve is 14 mm. so that the ports are uncovered and held wide open for the greater portion of the stroke of the piston, and begin to close only when the latter approaches the end of its stroke. In this way perfect freedom is given to the flow of the water and all choking is avoided. As the engine has been run at a speed of more than 688 revolutions per minute, the pump must have made at least 344 strokes in the same time, thus displacing 166.2 cc. of water. The diameter of the piston rod and valve stem is 3 mm. and they pass through stuffing boxes with glands of the ordinary type for packing. This pump served its purpose admirably, and with it it was possible to maintain a continuous circulation of water through the two coils of the boiler.

The third element in the steam-generating system is the boiler proper [2] (Plates 25 and 26A), which consists of two coils of copper pipe, having an outside diameter of 10 mm., each coil being formed of 21 turns each 75 mm. in diameter upon the outside and spaced 7.5 mm. apart, so that the total axial length of each coil is 36 cm.

The water is delivered to the front end of the right-hand coil, and, first passing through this, crosses over at the rear of the boiler to the left-hand coil, returning through it to the front whence it is led to and delivered into the top of the separator. Here the steam and water are separated, the former going through the separator and thence to the engine, while the unevaporated water falls to the bottom to be again taken into the pumps and sent through the coils.

In order that the draft of the burner and the gases of combustion might not be dissipated, it was necessary to sheathe the boiler. The method of doing this is shown in Plate 25. It will be seen that the front half of the boiler is wrapped in a sheet of mica through which the coils can be faintly seen. This, in turn, is held at the extreme front end by a strip of thin sheet-iron, *O*. Over the back end the stack *Q*, made of very thin sheet-iron, is slipped. This has an oblong cross-section at the lower end where it goes over the boiler; it is provided with a hole through which the midrod passes, and terminates in a circular opening of about 10 cm. diameter.

[2] The reader who may care to note the evolution of this boiler, by trial and error, will find a portion of the many discarded types shown in Plate 13.

The engine, which is clearly shown in the dimensional drawing, Plate 26B, is of the plain slide-valve type, using a piston valve and solid piston, without packing rings. The cylinder is formed of a piece of steel tubing 35 mm. outside diameter, with flanges 47 mm. in diameter and 2.25 mm. thick brazed to each end, to which the cylinder heads are attached by small machine screws. Inside this cylinder is a thin cast-iron bushing in order to obtain a better rubbing surface for the piston. The cross-head is a small piece of aluminum bronze, running on round guides that also serve as cylinder braces. There are also four hollow braces, 5 mm. in diameter, running from the back cylinder head to a corrugated steel bed-plate, that stands vertically and reaches from one side rod of the frame of the hull to the other, and to which are bolted the bearings of the main shaft. The connecting rod has the cross-section of a four-rayed star and drives a crank in the center of the shaft. The following are some of the principal dimensions of the engine:

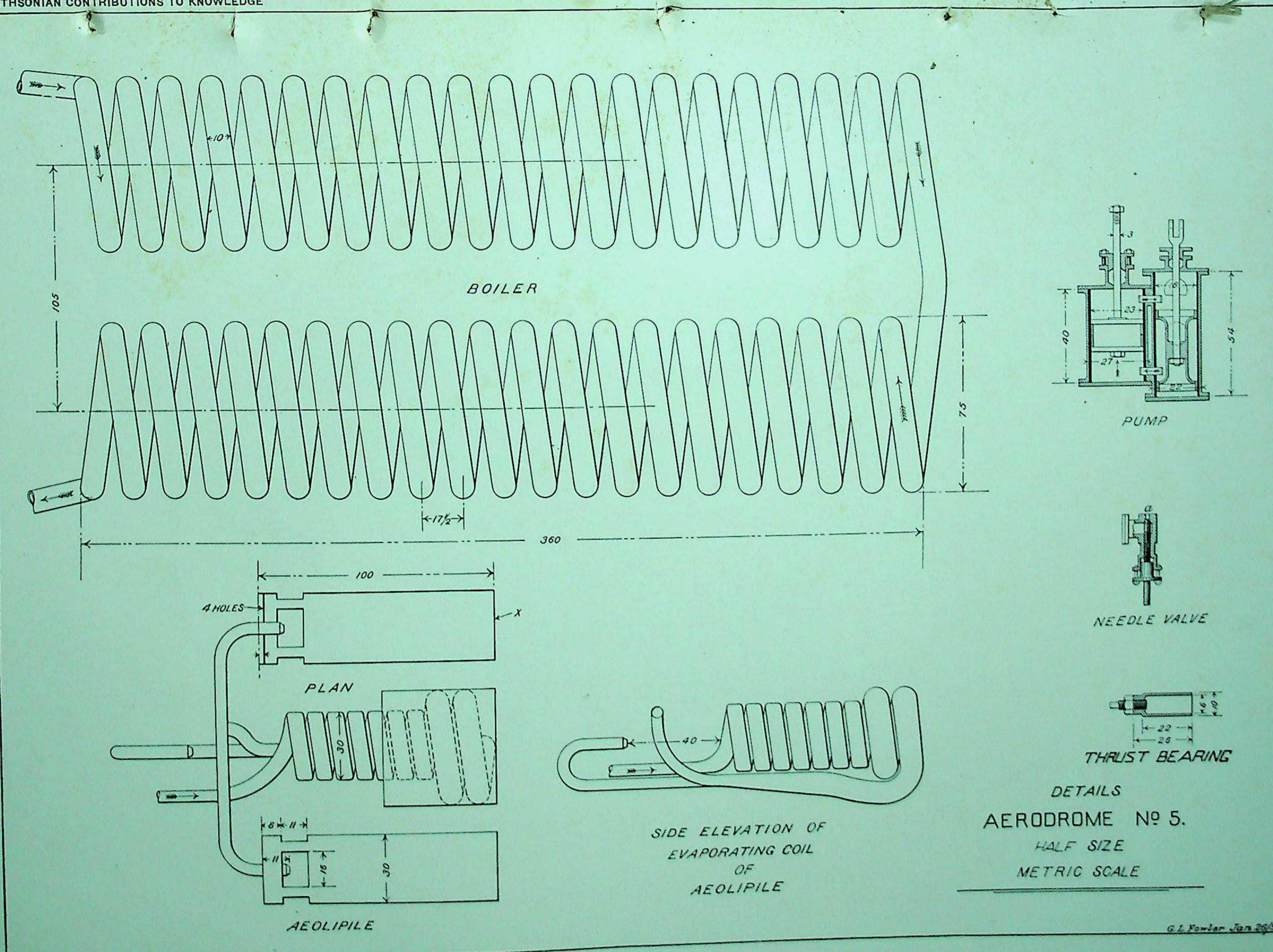
	millimetres.
Inside diameter of cylinder	33
Stroke of piston	70
Length of cylinder inside	88
Length of piston	11
Clearance at each end	0.5
Diameter of piston rod	5
Length of cross-head	17.5
Diameter of guides	4.5
Distance from center to center of guides	26
Length of guides	110
Length of wrist-pin bearing	8.5
Length of connecting rod	150
Ratio of connecting rod to stroke,	2 1/7 to 1
Length of crank-pin	10
Diameter of main shaft	8
Length of main bearings	25
Distance from center of cylinder to center of valve stem	35
Length of valve	72
Width of ports	2
Outside lap of valve	4
Inside lap of valve	3
Lead of valve	0
Travel of valve	13
Cut-off from beginning of stroke	57
Exhaust opens	End of stroke
Exhaust closes on return stroke	48
Diameter of valve stem	4.5
Diameter of eccentric	36
Width of eccentric	4
Width of crank-arm	4

The weights were nearly as follows:

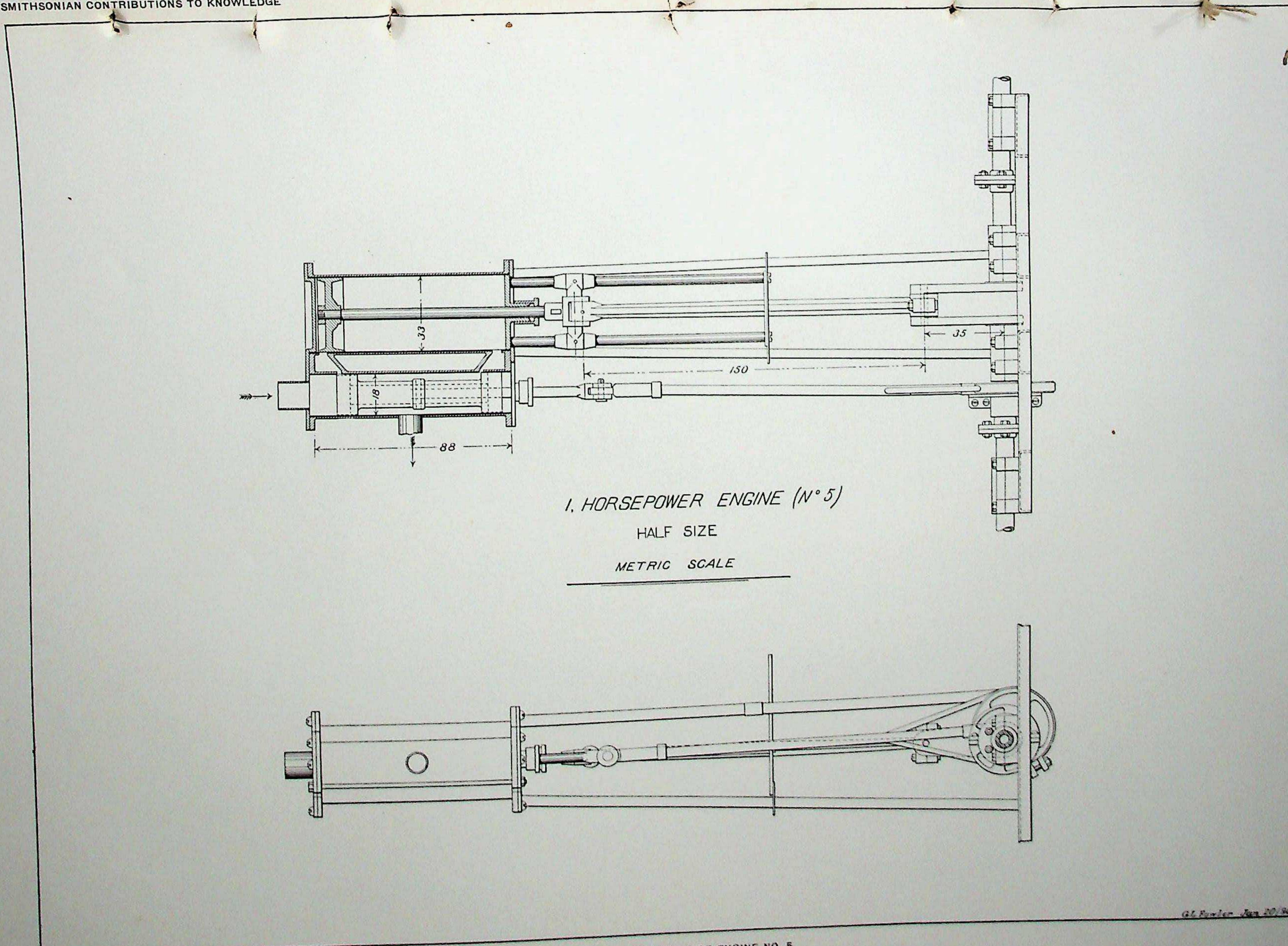
	grammes
Engine	464
Pump and pump shafts	231
Gasoline tank and valves	178
Burners	360
Boilers, frames holding boilers, and mica covers over boilers	651
Separator, steam gauge and pipe for engine	540
Exhaust pipe	143
Smoke stack	342

In all, 2909 grammes, or 6.4 pounds.

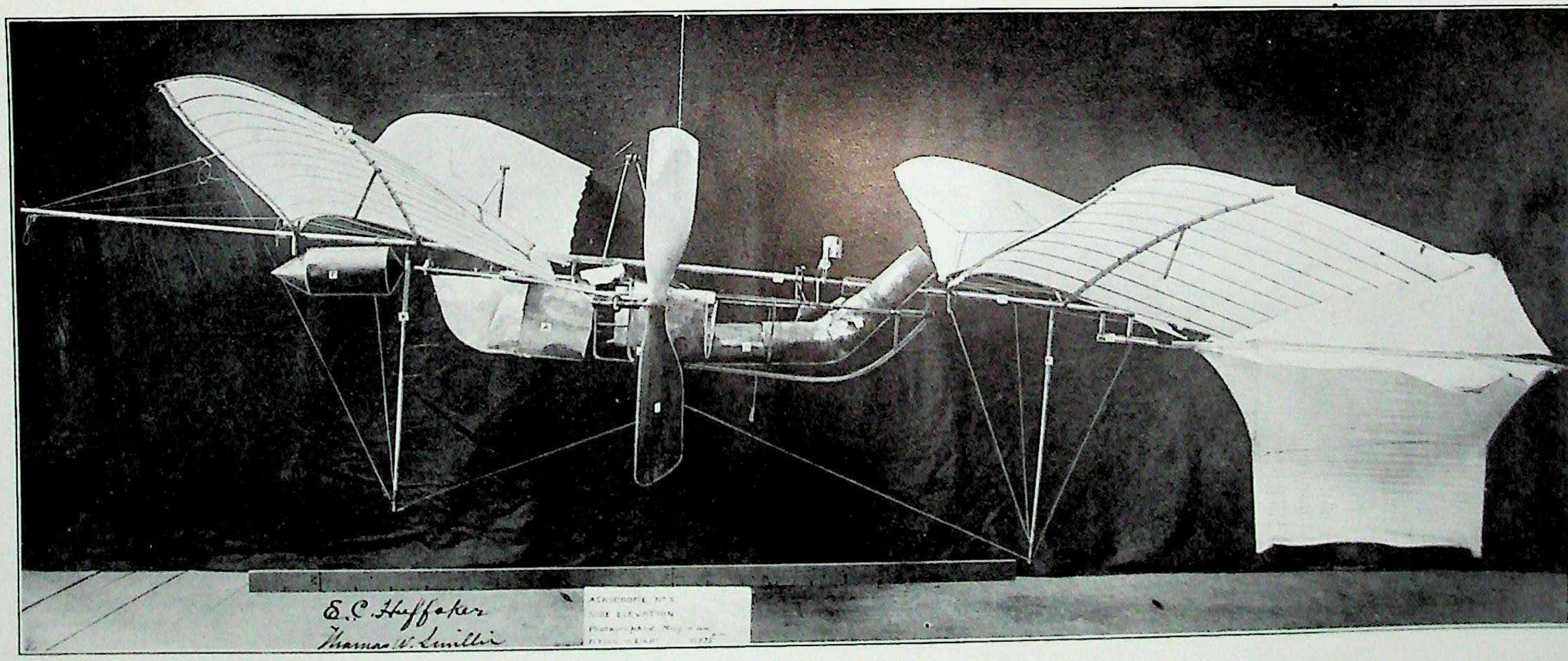
11

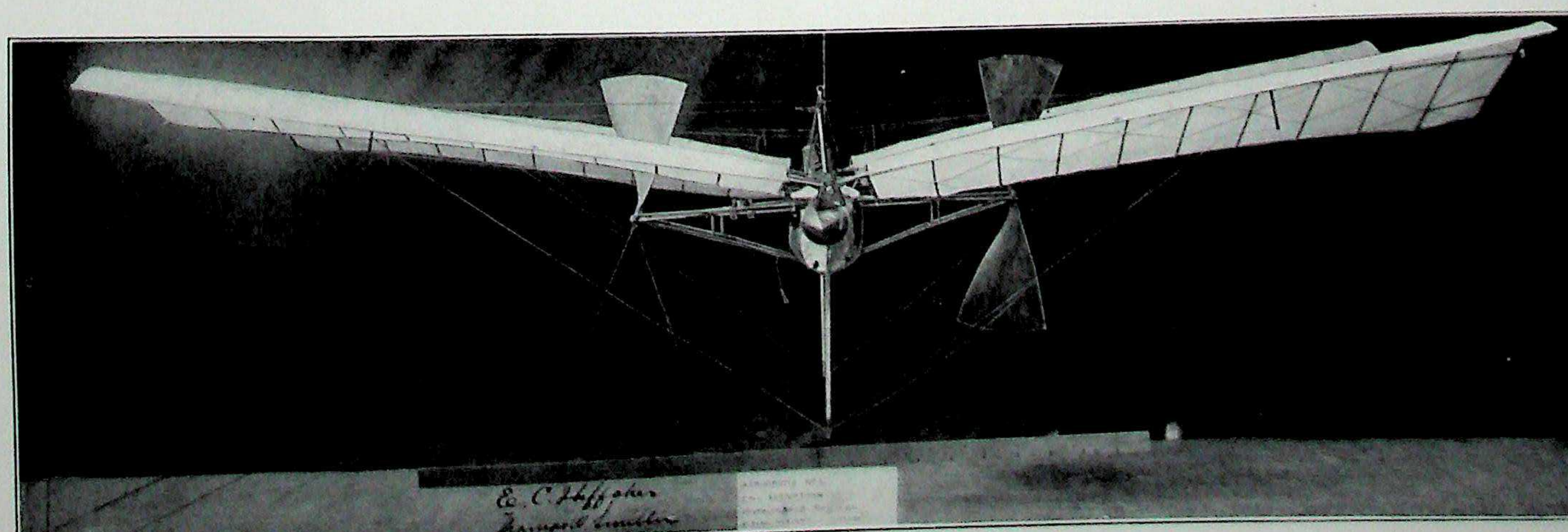


DIMENSIONED DRAWING OF BOILER COILS, BURNERS, PUMP, NEEDLE VALVE, AND THRUST BEARING

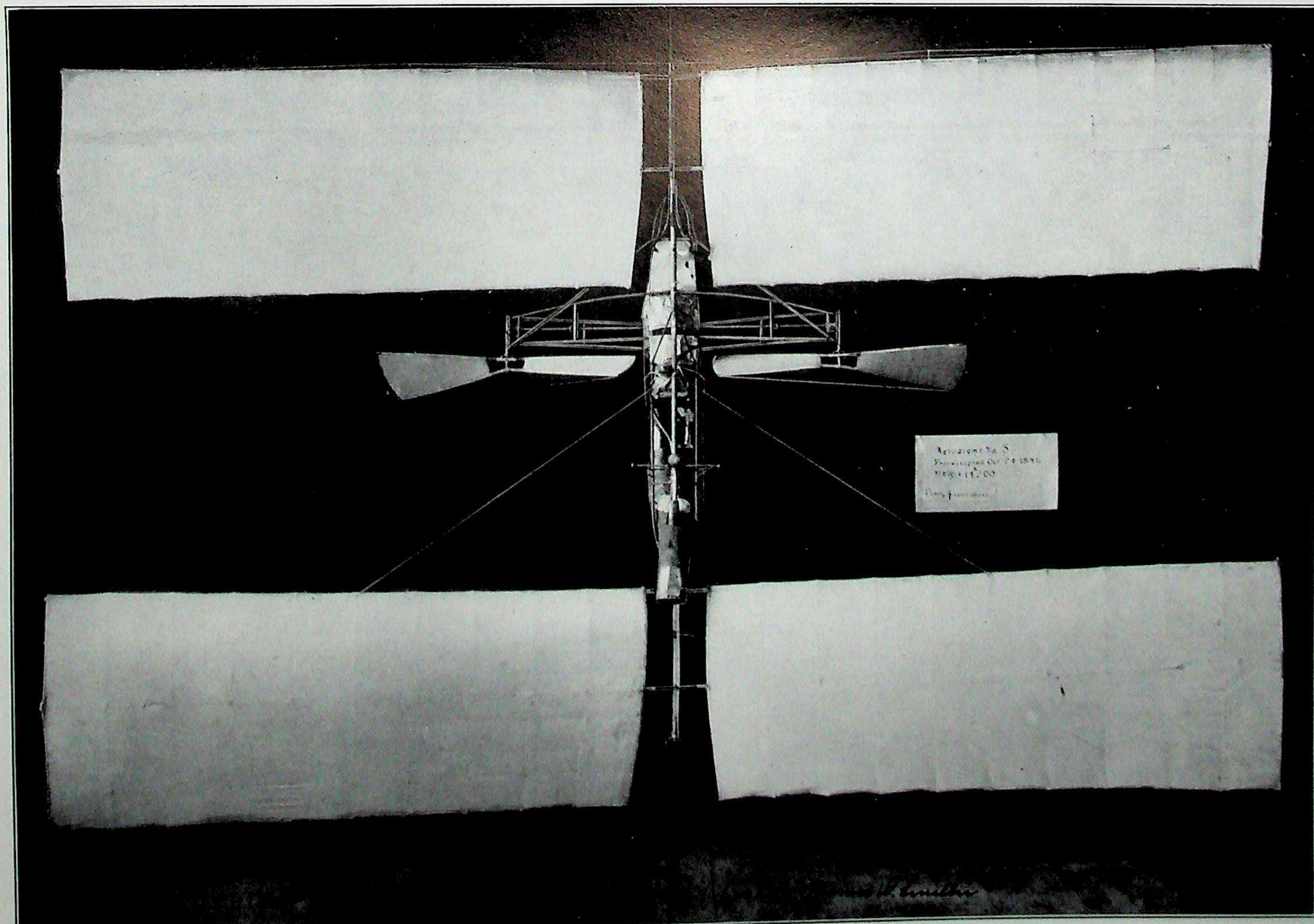


DIMENSIONED DRAWING OF ENGINE NO. 5





SIDE AND END ELEVATIONS OF AERODROME NO. 5, MAY 11, 1896



AERODROME NO. 5. PLAN VIEW. OCTOBER 24, 1896

These weights are those determined in December, 1896, when some slight changes had been made from the conditions existing at the time of the flight by this aerodrome on May 6. Previous to that time, with a pressure of 130 pounds, between 1.1 and 1.25 horse-power was given on the Prony brake. At the actual time of flight the pressure was about 115 pounds, and the actual power very nearly 1 horse-power.

The valve stem was pivoted to the center of the valve partly because this was the lightest connection that could be made, and partly to allow the valve perfect freedom of adjustment upon the seat. Many parts, such as guides, braces, crank-pins, wrist-pin and shafts, are hollow. The steam is taken in at the front end of the steam chest, and the exhaust taken out of the center, whence it is led back to the stack and by means of a forked exhaust pipe discharged in such a way as to assist the draught of each coil of the boilers. Like the cylinder the steam chest is made of a piece of steel tubing, 20 mm. diameter on the outside, with an inside diameter of 19 mm., and is fitted with a cast-iron bushing 0.5 mm. thick, making the inside diameter of the steam chest 18 mm. It, too, has flanges brazed to the ends, to which the heads are held by small machine screws.

The shaft for conveying the power to the propeller shafts extends across the machine from side to side; it is hollow, being 8 mm. outside diameter, with a hole 5 mm. diameter through the center.

It is formed of five sections: the middle section, containing the crank, has a length of 110 mm. and is connected at either end, by flanged couplings, to lengths 320 mm. long, which are in turn extended by the end sections having a length of 230 mm. In addition to the four main bearings that are bolted to the pressed-steel bed-plate already mentioned, there are two bearings on the outer framework on each side. At the outer end of each shaft there is keyed thereto a bevel gear with an outside diameter of 27 mm. and having 28 teeth. This gear meshes with one of 35 teeth upon a shaft at right angles to the main shaft and parallel to the axis of the aerodrome. These two shafts, one on either arm, serve to carry and transmit the power to the propellers. They are 192 mm. long, 8 mm. in diameter, and are provided with three bearings that are brazed to a corrugated steel plate forming the end of the outrigger portion of the frame. These shafts are also hollow, having an axial hole 4 mm. in diameter drilled through them. The propeller seat has a length of 43 mm. and the propeller is held in position by a collar 25 mm. in diameter at the front end, from which there project two dowel-pins that fit into corresponding holes in the hubs of the propellers, which are held up against the collar by a smaller one screwed into the back end of the shaft. The thrust of the collar is taken up by a pin screwed into the end of the forward box and acting as a step against which the shaft bears, the arrangement being clearly shown by the accompanying drawing, Plate 26A.

This, then, comprises the motive power equipment of the aerodrome, and, to recapitulate, it includes the storage, automatic feeding and regulation of the fuel; the storage, circulation and evaporation of the water; the engine to convert the expansive power of the steam into mechanical work; and the shafting for the transmission of the energy developed by the engine to the propellers.

The propellers were made with the greatest care. Those used in the successful trials were 1 metre in diameter, with an actual axial pitch of 1.25 metres. They were made of white pine, glued together in strips 7 mm. thick. The hub had a length of 45 mm. and a thickness or diameter of 25 mm. At the outer edge the blade had a width of 315 mm. and a thickness of 2 mm. These propellers were most accurately balanced and tested in every particular; each propeller blade was balanced in weight with its mate and the pitch measured at every point along the radius to insure its constancy; finally the two propellers of the pair to be used together were balanced with each other so that there would be no disturbance in the equilibrium of the machine. As will be noted from the foregoing description of the machinery, the propellers ran in opposite directions, as they were made right- and left-hand screws. The weight of each propeller was 362 grammes.

We now turn again to take up the details of the construction of the framework by which this propelling machinery is carried. The whole aerodrome, as clearly shown in the photographs, Plates 27A and 27B, is built about and dependent from one main backbone or midrod, which extends well forward of all of the machinery and aft beyond all other parts. This rod, as well as all other portions of the framework, is of steel tubing. The midrod, being largest, is 20 mm outside diameter, with a thickness of 0.5 mm. It is to this midrod that the wings are directly attached, and from it the hull containing the machinery is suspended.

The plan outline of the hull skeleton is similar to that of the deck of a vessel. The steel tubing, 0.5 mm. thick, of which it is formed, has an outside diameter of 15 mm. from the front end to the cross-framing used to carry the propellers, back of which the diameter is decreased to 10 mm.

The midrod makes a slight angle with this frame, the vertical distance between the centers of the tubing being 73 mm. at the front and 67 mm. at the back. The tube, corresponding to the keel of a vessel, is braced to the upper tubes by light U-shaped ribs and by two 8-mm. tubes forming a V brace on a line with the back end of the guides of the engine. At the extreme front and back there is a direct vertical connection to the midrod.

The propeller shafts are 1.23 m. from center to center, and are carried on a special cross-framing, partaking, as already stated, of the character of an outrigger on a row-boat. (See Plate 27B.) The rear rods, which are of 10 mm. steel tubing, start from the front end of the rear bearings of the propeller shaft and

extend across from side to side. The top rod is brazed to the side pieces of the hull and the bottom rod to the keel. They are connected by a vertical strut of 8-mm. tubing at a distance of 265 mm. inside of each propeller shaft. At the front end of the propeller shaft two more rods run across the frame. The lower is similar and parallel to the back rod already described, while the upper is bowed to the front, as shown in the plan view of the frame (Plate 30). In order to take the forward thrust of the propeller a second cross-brace is inserted, which runs from the rear bearing of the propeller shaft to a point just in advance of the front head of the cylinder, and is brazed to the two upper tubes of the cross-frame as well as to the upper tubes of the main framing of the hull. The outer ends of the tubes of the cross-framing are brazed to a thin, stamped steel plate which firmly binds them together, while at the same time it forms a base for attaching the bearings of the propeller shaft. This end plate has a thickness of one millimetre.

In addition to the framing proper there are two guy-posts which fit into the sockets *CC,* and over which truss wires are drawn, as shown in the side view in Plate 27A. These posts have a length of 730 mm. from the lower edge of the socket, and are capped at their lower extremity by a light steel ferrule whose outside diameter is 10 mm.

From the drawing of the wings of No. 5, shown in Plate 17, it will be seen that they are formed of two pine rods 15 mm. in diameter at the inner ends, tapering to a half circle of the same diameter at the tips. These rods are connected by eleven spruce ribs measuring 8 mm. × 3 mm., and curved, as shown in the side elevation, these, in turn, being covered by a light white silk drawn so tightly as to present a smooth, even surface. The total length of the wing is 2 metres, and the width over all is 805 mm. Vertical stiffness is obtained in the wings by a series of guy-wires, which pass over light struts resting upon the main rods. These main rods are inserted and held in the wing clamps *A* and *B,* Fig. 16, and make an angle of 150° with each other. As is the case with all other essential details of the aerodrome, a great deal of time and attention was given to the designing of the wing clamps before a satisfactory arrangement was secured.

To enable it to control the aerodrome in both directions, the tail-rudder, Plate 27A, has both a horizontal and a vertical surface, the approximate dimensions of which are, length 115 cm. (3.8 feet), maximum width 64 cm. (2.1 feet), giving each quarter section an area of about 0.64 sq. m. (6.9 sq. ft.). It is given the proper angle and degree of elasticity in a vertical direction by the flat hickory spring, which fits into the clamp *N,* and attaches the rudder to the frame.

The only other attachments of the aerodrome are the reel, float, and counter. They have nothing whatever to do with the flying of the machine, and are

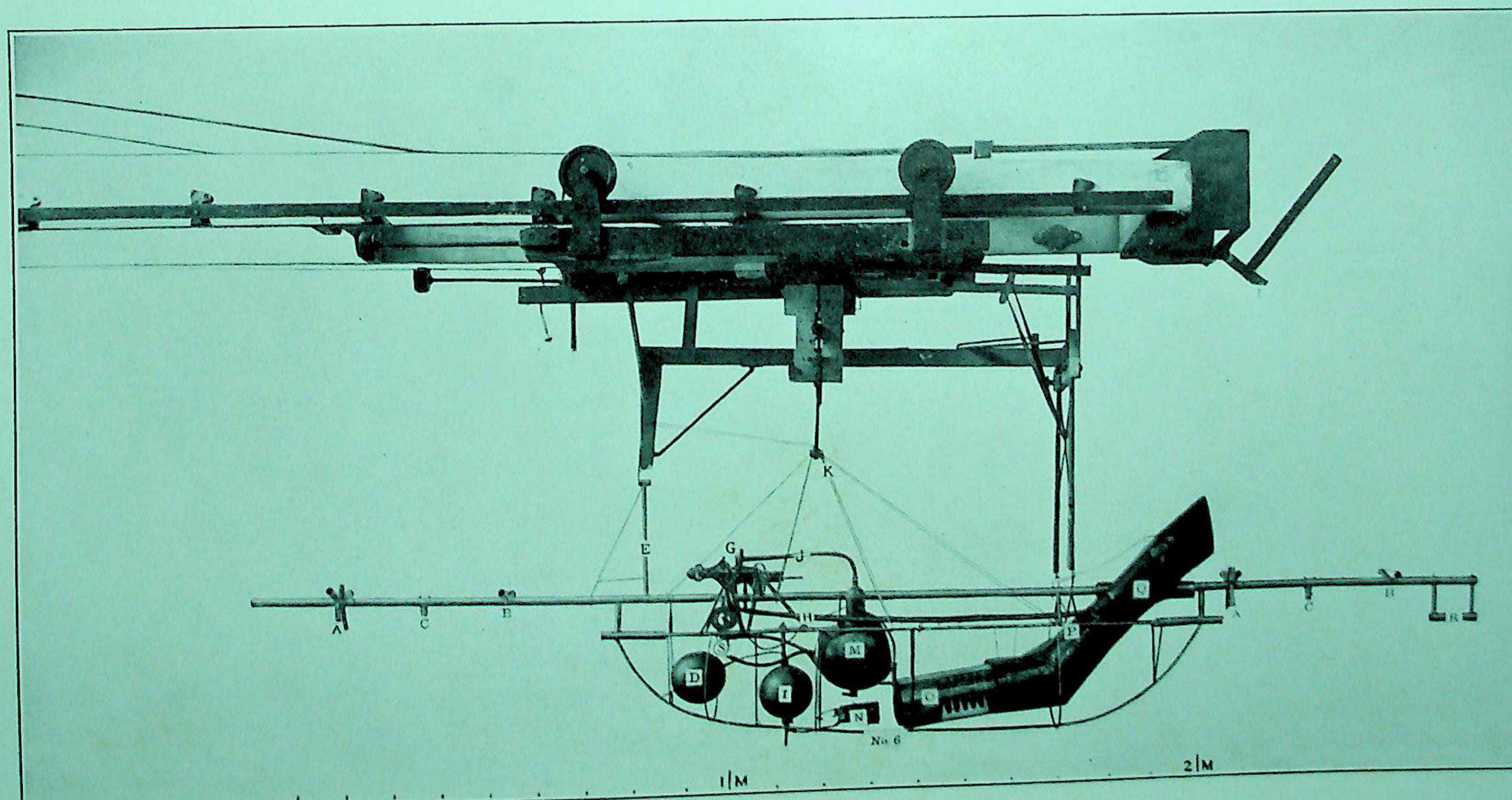
merely safety appliances to insure its recovery from the water. The reel consists of a light spool on which a fine cord is wound, one end of which is attached to a light float that detaches itself and lies upon the surface of the water when the machine sinks, while the other end is fastened to the spool that goes down with the aerodrome. The "float" is a light copper vessel with conical ends which is firmly fastened to the midrod, and which is intended to so lower the specific gravity of the whole machine that it will not sink. The cylindrical portion of this float has a length of 250 mm. and a diameter of 170 mm., one cone having a length of 65 mm. and the other and front one a length of 140 mm., which makes the total length of the float 375 mm. It is made of very thin copper, and served in the successful trials not only as a float to sustain the machine on the surface of the water, but also as a weight by which the center of gravity was so adjusted that flight was possible.

The counter records the number of revolutions of the propellers after launching. It is a small dial counter, reading to 10,000, with a special attachment which prevents any record being made of the revolutions of the propellers, until the actual moment of launching, when a piece on the launching apparatus throws the counter in gear at the instant that the aerodrome leaps into the air.

Description of Aerodrome No. 6

Aerodrome No. 6, it will be remembered, was the outgrowth of a number of changes made in No. 4 during the fall of 1895 and the early part of 1896. In this reconstruction the aim was to lighten the whole machine on account of the smaller engines used on No. 6, and to arrive at better conditions as regards stability than existed in either No. 4 or No. 5. The modifications from No. 4 were so radical and the differences that exist between Nos. 5 and 6 are so considerable as to demand careful attention.

As regards general appearance the frame of Aerodrome No. 6 resembles that of No. 5 in consisting of a single continuous midrod of steel tubing, 20 mm. in diameter, 0.5 mm. thick, immediately beneath which the hull containing the machinery is situated. In reconstructing the framework after the tests in January, 1896, had shown it to be dangerously weak, especially against torsion, it was decided to make the hull only strong enough to carry its contents and to attach it to the stronger midrod in such a way that all torsional strains would be taken up by it, whereas in No. 5 the hull structure must bear a large proportion of such strains. It was therefore built throughout of 8-mm. tubing, 0.3 mm. thick, and was rigidly attached to the midrod by braces at the front and rear, and also at the cross-frame. The hull was also made narrower (except at the rear, where it was widened to contain the boiler) and shorter than the hull of No. 5—an advantageous change made possible by the fact that the engines were not contained in the hull, but mounted on the transverse frame.



STEEL FRAME OF AERODROME NO. 6, ON LAUNCHING CAR

In No. 5, as described above, a single engine mounted at the front end of the hull communicated its power through transmission shafts and gearing to the propellers, which were necessarily in the same plane. This brought the line of thrust very nearly in the same plane as the center of gravity of the aerodrome, a condition tending to promote instability of longitudinal equilibrium. In No. 6, however, the use of two engines situated on the transverse frame and communicating their power directly to the propellers, made it possible to raise the transverse frame 12 cm. above the hull, and thus raise the line of thrust to a position intermediate between the center of pressure and the center of gravity, without materially affecting the latter. As a result of this change Aerodrome No. 6 was rendered much more stable and made steadier flights with fewer undulations than No. 5.

The engines in use on No. 6 were the small engines described above in connection with No. 4. The cylinders were of steel tubing 2.8 cm. in diameter, with a 5-cm. stroke, each cylinder thus having a capacity of 30.8 cc. They were lined with a thin cast-iron bushing and cast-iron rings were sprung in the piston head so as to give as smooth a rubbing surface and as perfect action as possible. As in the engine of No. 5 a plain sliding valve of the piston type was used, cut-off being approximately at one-half, though the ports were so small that it was difficult to determine it with any great accuracy. No packing was used, but the parts were carefully ground so as to give a perfect fit.

These engines, as is most clearly shown in Plate 30, were mounted symmetrically on either side of the cross-frame and were connected directly to the propeller shafts. In order to insure that the propellers would run at the same rate, there was provided a synchronizing shaft, *T*, in Plate 30, having on each end a bevel gear, which intermeshed with similar gears on the propeller shafts. Steam for the cylinders was conveyed from the separator through the pipes *LL*.

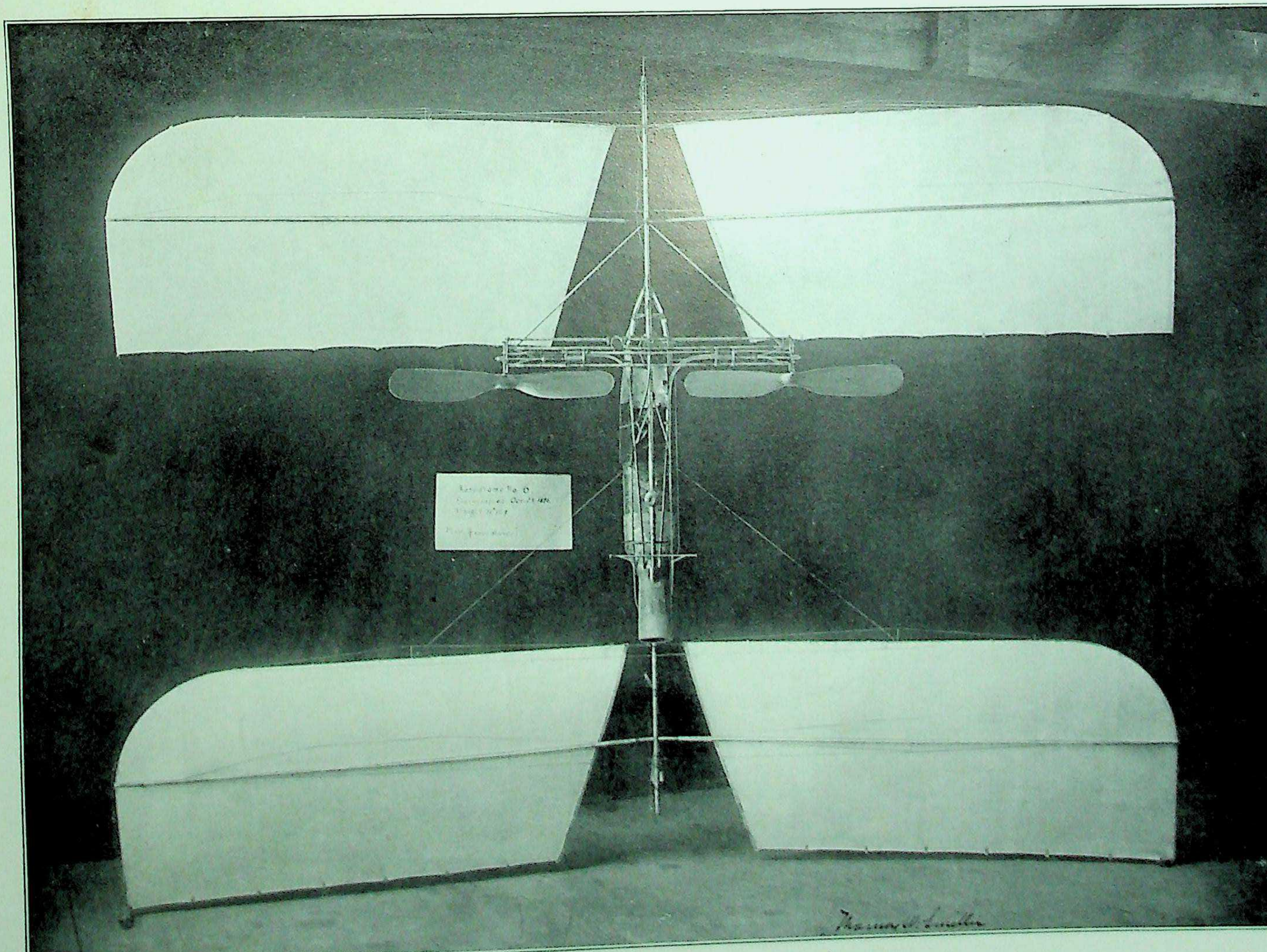
The steam-generating apparatus for No. 6 was exactly like that already described in connection with No. 5, the only difference being in the more compact arrangement in the case of No. 6. The relative location of the apparatus in the two models is clearly shown in Plates 28, 29B, and 30, the corresponding parts being similarly labeled, so that a separate description for No. 6 is superfluous.

The wings used on No. 6 were somewhat smaller than those of No. 5, and differed from them in having the front mainrib bent to a quadrant at its outer extremity and continued as the outer rib of the wing. The degree of curvature of the wings was also somewhat less, being one-eighteenth for No. 6 and one-twelfth for No. 5. The four wings were of the same size and had a total area of 54 sq. ft. On account of the shortened hull of No. 6 they were allowed a much greater range of adjustment, which rendered it much easier to bring the *CP* into the proper relative position to the *CG* than was the case with No. 5.

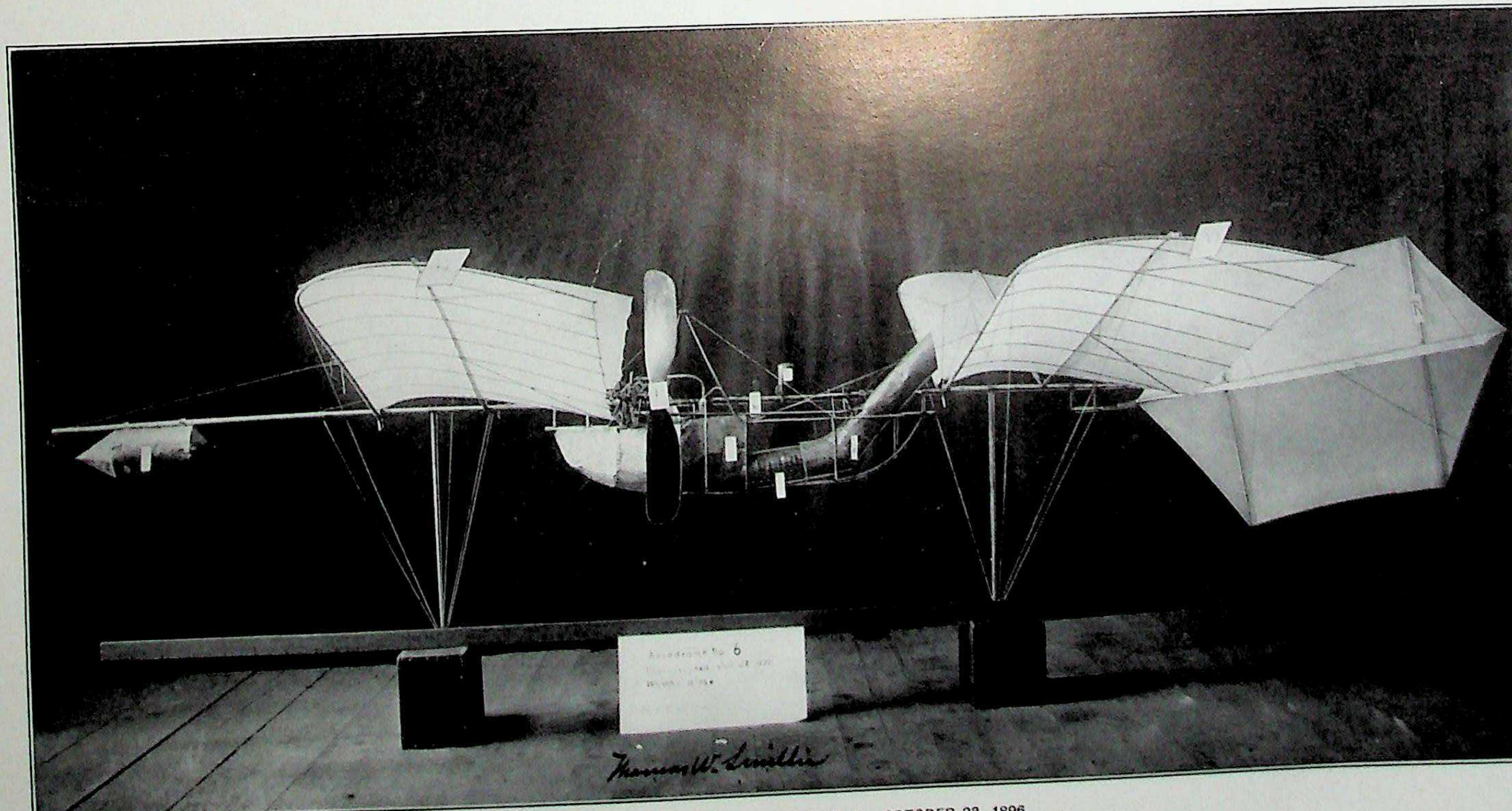
The Pénaud rudder for No. 6 was similar to that for No. 5, the two in fact being interchangeable, and was similarly attached to the frame. The reel, float, counter, and all other accessories were identical for the two machines.

To sum up the comparative features of these two successful steam-driven models: Aerodrome No. 6 was both lighter and frailer than No. 5, and required much more delicate adjustment, but when the correct adjustments had been made its flying qualities were superior, as regards both speed and stability.

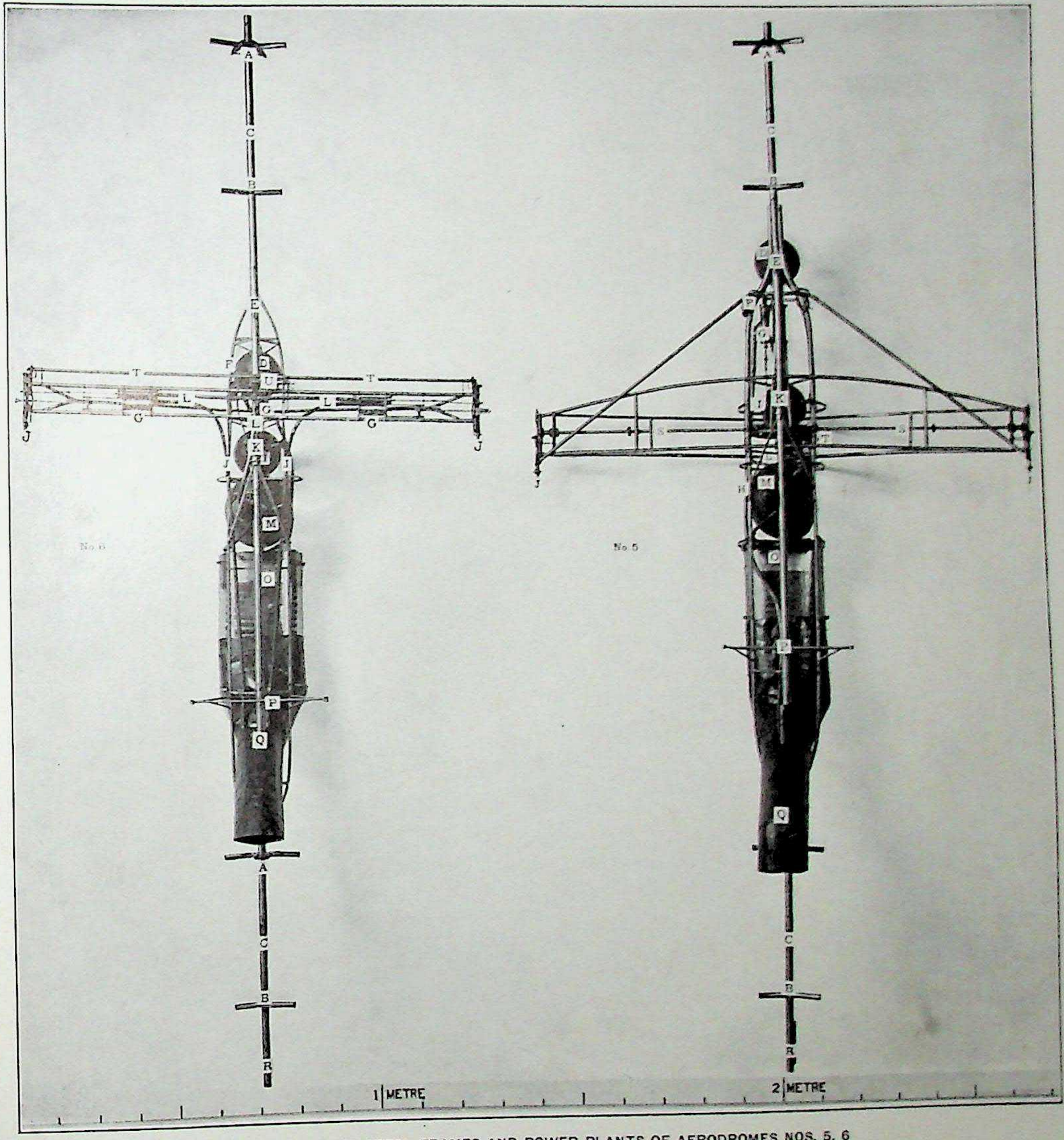
12b



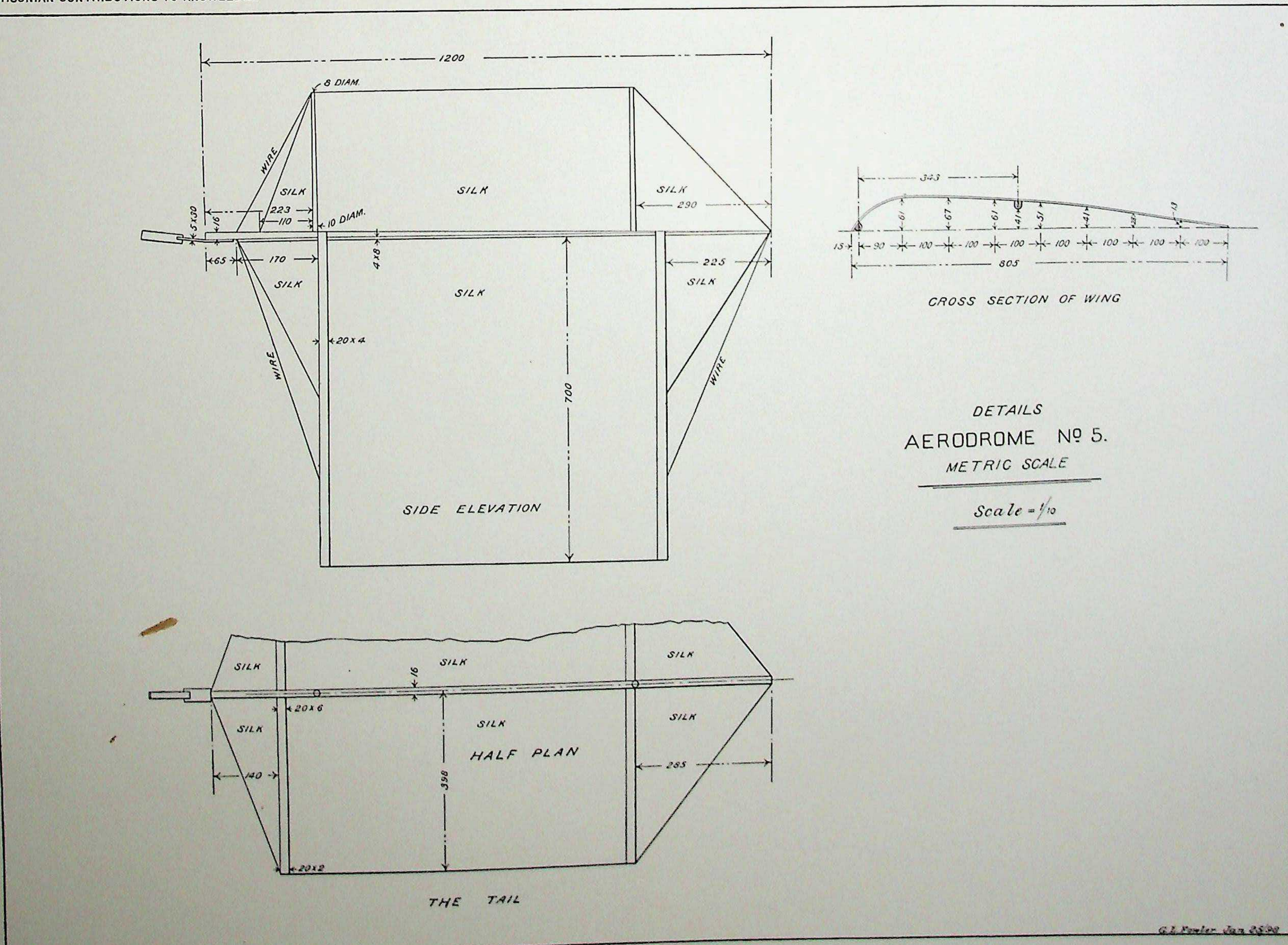
PLAN VIEW OF AERODROME NO. 6. OCTOBER 23, 1896



SIDE ELEVATION OF AERODROME NO. 6. OCTOBER 23, 1896.



PLAN VIEW OF STEEL FRAMES AND POWER PLANTS OF AERODROMES NOS. 5, 6



DETAILS OF AERODROME NO. 5

Part II. 1897 to 1903

By CHARLES M. MANLY
Assistant in Charge of Experiments

CHAPTER I

INTRODUCTORY

Although in 1896 Mr. Langley had made the firm resolution not to undertake the construction of a large man-carrying machine, as he realized that his multitudinous administrative duties left him practically no time available for original research, yet the longing to take the final great step of actually transporting a human being through the air, which the successful flights of the models had now for the first time in the history of the world actually proved to be possible, soon became irresistible.

Ten years of almost disheartening difficulties, a full appreciation of which can hardly be gained from the preceding description, had already been spent in demonstrating that mechanical flight was practicable, and Mr. Langley thoroughly realized that the construction of a large aerodrome would involve as great, if not even greater difficulties. Nevertheless, his indomitable will, which balked at no obstacle, however great it might seem, prevailed against the advice of his close friends and associates, and even that of his physician, who had counselled him that a resumption of concentrated thought and vigorous endeavor would materially shorten his life, which had already passed three score years. Only a few were privileged to come into close contact with him in his daily work, and thereby catch the inspiration of his unwavering persistence, his ceaseless perseverance, his plain inability to submit to defeat; but no one who has read the record of his astronomical expedition to Mt. Whitney, or the story of his development of the Bolometer, or the preceding chapters of this history of his years of patient work in the development of the flying machine, can have failed to obtain some appreciation of this most striking feature of his character. Having once determined on the accomplishment of a definite object, no amount of difficulty that might arise deterred him from pushing on until in some way and by some means he had succeeded; and no one appreciated better than he that if the thin edge of the right wedge can be inserted under an obstacle, that obstacle can be removed, no matter how formidable it may seem.

The undertaking of the construction of a large aerodrome was very largely influenced by President McKinley, who had become impressed with the great

possibilities of a flying machine as an engine of war. When he found that Mr. Langley was willing to devote his own time to the development of a machine, provided the Government would furnish the funds for the actual construction and tests of it, he appointed a joint board, consisting of Army and Navy officers, to investigate and report on the plans with which Mr. Langley had achieved success with the models. The report of this joint board of Army and Navy officers being favorable, the Board of Ordnance and Fortification of the War Department, at the direction of President McKinley, requested Mr. Langley to undertake the construction and test of a machine, which, while not expected to be a practical war machine, might finally lead to the development of such an engine of war. In this connection it is interesting to read a letter which Mr. Langley addressed to the Board of Ordnance and Fortification at the time he undertook this work.

SMITHSONIAN INSTITUTION, December 12, 1898.

The Board of Ordnance and Fortification, War Department.

GENTLEMEN: In response to your invitation, I repeat what I had the honor to say to the Board—that I am willing, with the consent of the Regents of this Institution, to undertake for the Government the further investigation of the subject of the construction of a flying machine on a scale capable of carrying a man, the investigation to include the construction, development and test of such a machine under conditions left as far as practicable in my discretion, it being understood that my services are given to the Government in such time as may not be occupied by the business of the Institution, and without charge.

I have reason to believe that the cost of the construction will come within the sum of $50,000.00, and that not more than one-half of that will be called for in the coming year.

I entirely agree with what I understand to be the wish of the Board that privacy be observed with regard to the work, and only when it reaches a successful completion shall I wish to make public the fact of its success.

I attach to this a memorandum of my understanding of some points of detail in order to be sure that it is also the understanding of the Board, and I am, gentlemen,

With much respect,
Your obedient servant,
S. P. LANGLEY.

MEMORANDUM

ATTACHED TO MY LETTER OF THIS DATE TO THE BOARD OF ORDNANCE AND FORTIFICATION

While stating that I have, so far as I know, an exclusive right of property in the results of the experiments in aerodromics which I have conducted heretofore and am now conducting, and while understanding that this property and all rights connected with it, whether patentable or otherwise, will remain mine unqualifiedly, I am glad to place these results, without charge, at the service of the Board of Ordnance and Fortification for the special construction at present proposed, which seems to me to be of National utility.

I assume that no public statement will be made by the permission of the Board until the work is terminated, but that I may publish ultimately at my discretion a statement of any scientific work done in this connection.

I understand that the exercise of this discretion includes the ordering and purchase of all material by contract or in open market, and the employment of any necessary help, without restriction, and that, while I desire that no money shall pass through my hands, itemized bills for each expenditure, made in proper form and approved by me, will be paid by the Chief Signal Officer.

Much has already been spent at the Smithsonian Institution for the purpose in question, in special apparatus, tools and experiments, and in recent constructions now actually going on, which have involved still more time than money, and which are essential for experimental use in building the proposed machine; and since to re-create all this independently would greatly defer progress, I assume that my discretion includes the decision as to how far this shall be used and paid for at the cost of this allotment (it being understood that I have no personal property in any of the material which might be transferred for the purpose of the work); and I also assume that my discretion includes the decision as to where the work shall be conducted—that is, whether in shops already constructed, or in others to be elsewhere erected or rented, with the necessary adjuncts, whether on land or water, and generally whatever is necessary to the earliest attainment of the object desired by the Board.

S. P. Langley.

Smithsonian Institution, Washington, D. C.,
December 12, 1898.

As is always the case in experimental work, especially in a field so very new as was the field of aerodromics at the time that this larger construction was undertaken, the " plant," or shops and laboratories required for the constructional and testing work, grew to a size far beyond what seemed even remotely possible at the beginning of the work; and even the mere administration involved in the carrying on of this work proved to be no inconsiderable matter before it had progressed very far.

The years of experiment with the models had demonstrated clearly that the greatest difficulty in the development of the aerodrome was the construction of a suitable power generator, which should combine the elements of extreme lightness and unusual power with a fair degree of durability. Although remarkably good results had been secured in the case of the models through the use of steam, it was realized from the first that not only would the development of a steam-power plant for a large man-carrying aerodrome present difficulties of a constructional nature, but that such a steam plant would necessarily be so fragile and delicate as to make it a constant menace to the machine which it was to propel. The solution of the difficulty, it was believed, was to be found in the use of an internal combustion engine; but Mr. Langley had had very little experience with such engines, and was averse therefore to undertaking the construction of a large aerodrome until he had assurance that a suitable gasoline engine could be secured. Before making an agreement to attempt the work for the War De-

partment, he had, therefore, made a search for a reliable builder who would undertake to construct a gasoline engine of not less than 12 horse-power to weigh not exceeding 100 pounds, and what then seemed a safe contract had been entered into with such a builder to supply one engine which would meet these requirements.

Almost immediately before the Board of Ordnance and Fortification had officially placed the work in Mr. Langley's hands and had made an allotment of fifty thousand dollars to meet the expenses thereof, it was found that the engine builder could not be depended on, and that it would, therefore, be necessary to find one who was more reliable and more experienced in the construction of light engines. After a most extended search for the best builder to undertake this work, a contract was entered into on December 12, 1898, with Mr. S. M. Balzer, an engine builder in New York City. He was to furnish a twelve-horse-power engine to weigh not more than 100 pounds, and delivery of it was to be made on or before February 28, 1899. With this great problem of the engine apparently provided for, every facility of the Institution shops was pressed to the utmost limit in order to have the frame, supporting surfaces, launching apparatus, and other accessories ready as soon as possible after the delivery of the engine. It was expected from the first that more power would be necessary than this one engine would furnish, and provision had been made in the contract that a duplicate engine should be constructed immediately after the completion of this first one. From past experience, however, it was not likely that the correct balancing of the aerodrome could be determined from *a priori* calculation based on the results obtained with the models, and it was, therefore, expected that the aerodrome would have to be launched several times before a successful flight could be obtained. In view of this it was planned to make a test of the machine as soon as the first engine was ready, with the expectation that, while the aerodrome would not have sufficient power to fly, yet the test would furnish definite data on the all-important question of balancing, and also determine whether or not the launching apparatus would require modification. In fact, Mr. Langley felt so apprehensive that the first, and possibly the second test, would be unsuccessful that, in order to avoid the possibility of a fatal accident, it was planned that a dummy should be used to represent the weight of the man in these preliminary tests.

This plan, however, was not carried out. In 1903, when the large aerodrome was finally completed, so much time had been lost that the writer proposed to assume the risks of such an accident and to guide the machine in its first test, in the hope of avoiding a disaster, with the consequent delay of months for repairs, which the presence of a controlling hand capable of correcting any inaccuracies of balancing rendered far less likely to occur. To this proposal Mr. Langley assented with great reluctance, as he fully realized the danger involved.

Particular attention is called to the above facts, which clearly show that while a certain degree of success in the initial tests was later hoped for, yet from the beginning it had been felt rather certain that several tests would have to be made before final success would be achieved.

To those experienced in scientific experiments this realization of the probability of several tests being necessary before success could reasonably be expected does not seem strange, for the record of past experience contains very few examples of epoch-making inventions springing full fledged from the hand of their maker and proving a success on the first test.

The two experiments made in the fall of 1903, in which the aerodrome was each time so damaged in the process of launching that its ability to fly was never really tested, should therefore be considered merely as the first of a series which it had been expected would need to be made before success would be achieved. Further tests were made impossible at the time on account of the lack of funds, the expense of such work being unusually heavy.

While the lack of funds, therefore, was the real cause of the temporary suspension of the work, yet an influence which does not often enter into scientific work—the unjust criticism of a hostile press—was directly responsible for the lack of funds. It seems very certain that had it not been for this criticism of the press the funds would have been readily forthcoming for continuing the work to the point of success.

CHAPTER II

GENERAL CONSIDERATIONS

In the development of man-carrying flying machines two well-defined paths are open. First: Starting with gliding machines, in which gravity furnishes the motive power, the operator may by practice acquire sufficient skill in controlling them to warrant the addition of propelling mechanism, and individual skill in control may be gradually replaced by automatic controlling mechanism. Second: From self-propelled models, possessing automatic-equilibrium controlling mechanism, and of a sufficient size to furnish determinative data, one may, by proper modification in size and construction, progress to an automatically controlled man-carrying machine in which, for ideal conditions, no especial skill on the part of the operator is required. Each method has its advantages.

After concluding his earlier and purely physical researches, the results of which were embodied in "Experiments in Aerodynamics," Mr. Langley was so firmly convinced of the practicability of mechanical flight that he undertook the construction of the model aerodromes in order to demonstrate it. It is very doubtful if at any time, prior to the successful flights of the models in 1896, he seriously contemplated the construction of man-carrying machines. His object in developing the models was not, therefore, to furnish a prototype for a large machine, but merely to demonstrate the feasibility of mechanical flight; and this he did. This is shown very clearly by the closing remark of the article he published in 1897, describing the flights of the models. "I have now brought to a close the portion of the work which seemed to be specially mine—the demonstration of the practicability of mechanical flight—and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others."[1] When he later undertook the construction of the large machine for the War Department it was natural that, with the inspiring sight of the models in flight still fresh in his mind, he determined to use as a prototype these successful machines, which were the only things of human construction that had ever really flown for any considerable distance.

Not being an engineer, and realizing that to pass from the construction of models to that of man-carrying machines involved the solution of many engineering problems, Mr. Langley, in the spring of 1898, sought the advice of Dr. R. H. Thurston, who had from the first manifested the deepest interest in his

[1] "The Flying Machine" *McClure's Magazine*, June, 1897.

work in aerodromics. On the recommendation of Dr. Thurston he engaged the services of the writer, who assumed charge of the work in June, 1898.

While the method of "cut and try" had brought success in the models, and was perhaps the only method by which they could have been successfully developed, it was thought that, with these models as a basis of design, much time would be saved by making an analytical study of them as engineering structures, and from the data thus obtained the proper proportions for the parts of the larger machine could be calculated.

Such an analytical study, however, revealed very little from which to make calculations as to the strength necessary for the various parts of the large machine, but it did show very clearly that most of the parts were working under stresses generally far above the elastic limit of the materials, and in many cases the ultimate breaking strength was closely approached. Such a condition was the natural outcome of the method by which these models had been developed—all the various parts having been built at first of the least possible weight and, when they proved too weak, strengthened until they would withstand the stresses imposed on them. It is extremely doubtful if previous calculations as to the strength necessary would have been of any assistance, in fact it is probable that it would have been a distinct disadvantage and would have resulted in the machines being entirely too heavy for flight.

The exact strength which had been incorporated in the frames of the models was as unknown as was the exact amount of the stresses which they had been made to withstand. Their static strength was easily determined by calculation, but the stresses due to the live loads were incapable of exact determination from the available data, for stresses produce strains, which in turn generally cause distortions accompanied by greatly increased stresses. While exact data were, therefore, lacking as to stresses and strengths in many of the important parts, yet the models furnished most important illustrations of unusual strength for minimum weight, and a careful study of them showed many ways in which increased strength could be obtained with decreased weight which could hardly have been devised without these concrete examples.

It was, however, by no means possible to build the large aerodrome within the permissible limits of weight by simply increasing the various parts of the models according to some predetermined function of the size of the whole.

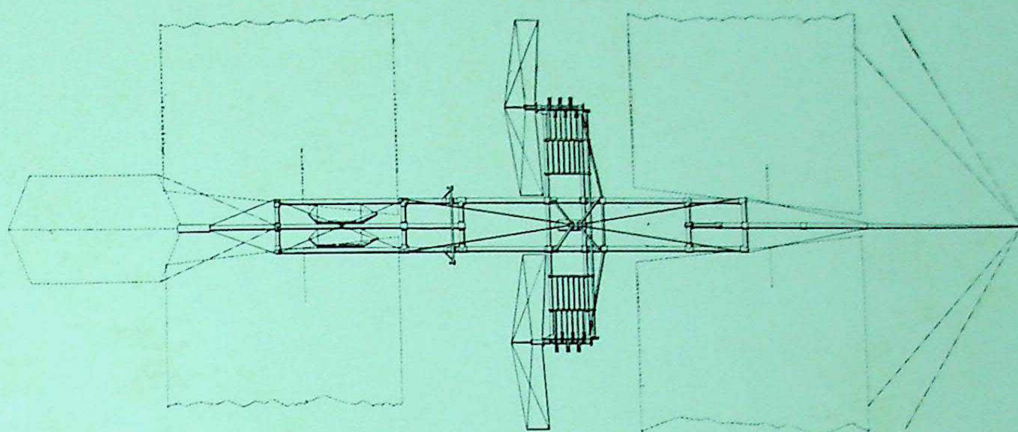
The fundamental difficulty is that inevitably, by the laws of geometry, which are mere expressions of the properties of space, if a solid of any form is magnified, the weight increases as the cube, while the surface increases only as the square, of the linear dimensions. Successive generations of physicists and mathematicians pointed out that while this "law of the cube" is of advantage in the construction of balloons, yet it is a stumbling block that will prevent man

from ever building a dynamic flying machine sufficiently large to carry even one human being.[2]

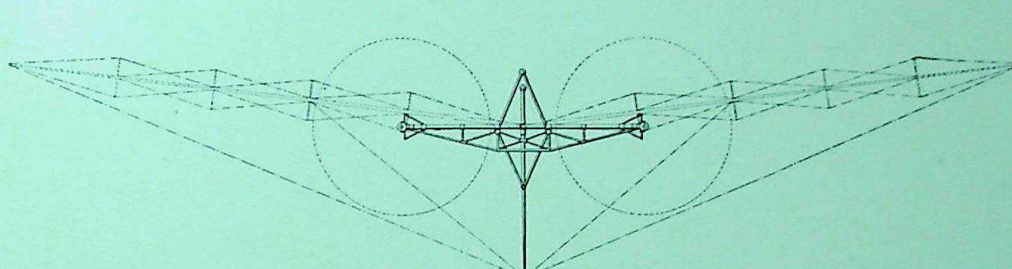
However, since strength is a function of material and form rather than weight, it is possible by selecting proper materials and adopting suitable structural forms to evade to a certain extent this "law of the cube." The whole history of structural science has therefore been a series of attempts to find stronger and lighter material and to discover methods of so modifying form as to dispense with all parts of a structure that do not contribute to its strength. So in aerodromics the structural problem has been that of finding materials and forms best suited to the purpose for which they are required, for it does not always follow that either the form or the material best suited for one scale of construction is the most advantageous to employ on a different scale. Nor is even the form or material which gives the greatest strength for the least weight necessarily the best to employ. For the structural problem must necessarily be co-ordinated with those of balancing, propelling, and transporting, and each must, therefore, have its proper attention in the design of the whole machine.

Many of the general considerations of the design of an aerodrome sufficiently large to transport a man were determined during the spring and summer of 1898, when the first actual drawings (Plate 32, Figs. 1, 2 and 3) of the proposed machine were made. Starting with the assumption that the Models Nos. 5 and 6 were capable of transporting a load of approximately ten pounds more than their weight, it was seen that, since the supporting surface of any aerodrome would increase approximately as the square of the linear dimensions, in order to carry a man the aerodrome would need to be approximately four times the linear dimensions of these models. Calculations based on the results accomplished in the construction of the models indicated that such an aerodrome would need to be equipped with engines developing 24 horse-power. The best that could reasonably be hoped for was that these engines would not weigh over 200 pounds, and, therefore, allowing 40 pounds for fuel and fuel tanks, it became necessary to bring the weight of frame, supporting surfaces, tail, rudder, propellers and every other accessory within 250 pounds, if the total weight of the machine, including 150 pounds for the aeronaut, was not to exceed 640 pounds, or 16 times the combined weight of the model and its load of 10 pounds. Although the problem of constructing the frame, wings and all other parts within the limit of 250 pounds seemed indeed formidable, it was believed that the greatest obstacle in the production of such a machine would be that of securing a sufficiently light and powerful engine to propel it.

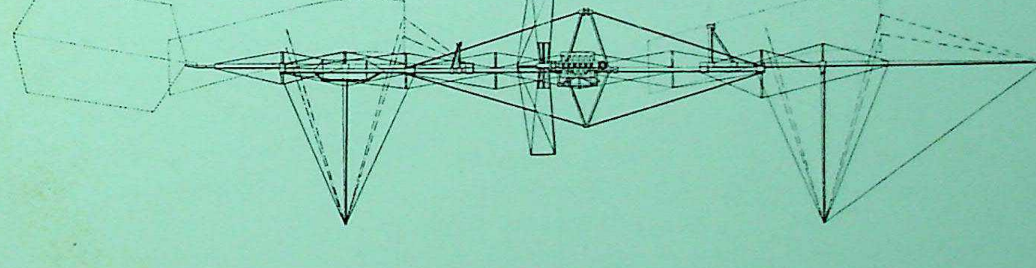
[2] One noted astronomer and mathematician re-affirmed this opinion as late as 1900 and even stated that man could not hope to construct a flying machine capable of sustaining a weight as great as our largest birds, not knowing that even at that time the model Aerodromes Nos. 5 and 6 had already done more than this.



PLAN.



TRANSVERSE SECTION



SIDE ELEVATION.

SCALE
0 1 2 3 4 5 6 7 8 9 10 FT

DRAWINGS OF PROPOSED MAN-CARRYING AERODROME, 1898

A brief account has already been given of the attempts made by Mr. Langley to secure a suitable gasoline engine for the large aerodrome, but the difficulties encountered in the search have not perhaps been sufficiently emphasized. At this time (1898) the automobile industry, through which has come the development of the gasoline engine, was in its infancy, and there were few builders either in the United States or Europe who were attempting anything but rough and heavy construction. Many of them were enthusiastic over the possibilities of the internal combustion engine, and were ready to talk of devising such an engine as the aerodrome would require, but few were willing to guarantee any such definite results as were demanded. However, the prospects of securing a suitable gasoline engine from a reliable builder within a reasonable time seemed so strong that it was decided early in 1898 to begin the construction of the frame on the general plan which would probably be best adapted for use with a gasoline engine, and in case it finally proved impossible to secure such an engine, to construct later a steam plant which could be adapted to this particular frame.

Some tentative work on the construction of the frame was accordingly begun in the summer of 1898, some months before an engine builder was found who seemed likely to be successful in furnishing the engines. An extensive series of tests on propellers was also made at this time for the immediate purpose of determining what form and size would be best, since the dimensions of the transverse frame could not be definitely settled until it was known how large the propellers would need to be.

Preliminary designs were also begun for the wings, rudders, and launching apparatus, but when the point was reached of actually making the working drawings for these, it was seen that the change in the scale of the work required many important modifications in constructional details. As the models had flown successfully only three times, and in each case under practically the same conditions, it was felt that it would be unwise to make changes in important details without first making a series of tests of the models in flight to determine the effect of such changes. It was therefore decided to completely overhaul Models Nos. 5 and 6, strengthening them in many important parts and "tuning up" their power plants, which had slightly deteriorated since they were last used in November, 1896. When the work of preparing these models for further experiments was begun it was thought that it would require at most only a few weeks, but as it progressed it was found that certain parts of the mechanical work on the engines had been so poorly executed originally that it would be necessary to practically rebuild the engines. The final result was that the power plants of both aerodromes were entirely rebuilt, and they were not ready for actual test in flight until the spring of 1899.

Much of the preliminary work necessary for the determination of actual working plans was therefore completed in the summer and fall of 1898, and when on December 12 a seemingly satisfactory contract for the engines for the large aerodrome had been made it was thought that rapid progress could be made on the constructional work after January 1, 1899, when the allotment from the War Department would become available.

CHAPTER III

EXPERIMENTS WITH MODELS

Immediately after the contract for the engine had been placed and the actual work had been begun, attention was given to the problem of providing means for properly launching the aerodrome. On the theory that the plan of launching the small aerodromes, which had finally been adopted after many years of painstaking experiment, would be the best to employ for the large aerodrome, Mr. Langley decided to have constructed a large house-boat with the launching track arranged on it in a way similar to that used for the small machines. While the general plans for this boat had been under consideration for some time, the actual working drawings were completed in January, 1899, and so great seemed the need for expediting its construction, in order to have it ready at the time when the engine was expected, that the contract which was made for its construction specifically provided for its being completed promptly, there being a large forfeit to cover any delay on the part of the contractor.

While the boat itself was being constructed, the working drawings were completed for the house to be built on it, and a contract was made for the construction of this house within a given period, there being also a time forfeit in this contract.

When the end of February arrived, it was found that, although the engine builder had succeeded in constructing an engine which weighed one hundred pounds, and which theoretically should have given something over twelve horse-power, yet he was unable to make it work properly. And then began a protracted period of most exasperating delays, the engine builder promising from week to week that certainly within the succeeding ten days he would be able to make delivery of the engine developing the full horse-power for which the contract called. After this delay on the engine had continued for some months—a delay which necessitated the cessation of the work on the main steel frame of the aerodrome, as it was deemed best to make certain tests of the engine running while supported by a portion of the frame to determine whether or not it was strong enough before completing the rest of it—Mr. Langley decided to employ part of the time in the construction of a model of one-eighth the linear dimensions of the large aerodrome, which was to be used in testing a model of the newly designed launching apparatus described later, and which might also be flown as a kite in making check measurements on the proper balancing which should be employed for the large aerodrome.

The perfected launching apparatus which had been used for the steam-driven models Nos. 5 and 6 (described in Part I, Chapter X) had proved most satisfactory and reliable, but when the designs were made for a launching apparatus for the large machine it was found that an exact duplication of the plan of the small one involved serious difficulties in connection with the construction of the house-boat, owing to the very considerable weight and size of the turn-table necessary to permit the aerodrome to be launched in any desired direction, regardless of the direction in which the house-boat might be pointing under the influence of the wind and tide. A new design was accordingly made for a launching apparatus in which the launching car was to run on a track mounted directly on the turn-table, the launching car supporting the aerodrome from underneath, instead of being mounted in an inverted position on an overhead track with the aerodrome depending from it.

From the previous description of the launching apparatus, it will be recalled that, in order to provide that the aerodrome should drop slightly at the moment of its release from the car, and thereby avoid all danger of entanglement, the speed of the launching car at the point at which the aerodrome was released was purposely made *less* than the "soaring speed" of the aerodrome. Having this feature in mind, when designing the "underneath" launching apparatus, it was recognized that the danger of the aerodrome becoming entangled with this form of apparatus could be avoided by making the launching speed *greater* than the velocity which it would be necessary for the aerodrome to have in order to soar, *provided the balancing was correct and the aerodrome did soar*. Nevertheless, it was deemed unwise to put too much dependence on the empirical calculations from which the balancing of the large aerodrome would necessarily be determined, and, therefore, some means seemed necessary for causing the launching car to drop out of the way immediately upon releasing the aerodrome. In the new design, more completely described below, in Chapter IV, this was accomplished by so arranging a portion of the front end of the track that, at the moment the launching car released the aerodrome, it dropped like a disappearing gun carriage, leaving the aerodrome free in the air with no possibility of becoming entangled, provided the aerodrome itself did not drop more rapidly than an angle of 15 degrees.

A small working model of this launching apparatus, one-eighth the linear dimensions of that which would be necessary for the large aerodrome, was first designed and constructed in the shop, the small one-eighth-size model of the large aerodrome being launched from it into a sheet stretched in front of it to act as a buffer. When it was found to work very satisfactorily, a large one, twice this size, was immediately built for use with the steam-driven models Nos. 5 and 6.

These models, Nos. 5 and 6, which had flown so successfully in 1896, had, during the preceding twelve months, been completely overhauled and thoroughly tested in preparing them for trials in actual flight. Many pendulum tests were made on both aerodromes, and it was found after repeated trial that each could be depended on to show a lift of sixty per cent of its flying weight.

This was more than sufficient for flight, but in order to insure successful trials and avoid delay no aerodrome was launched until it had shown previously its ability to generate enough power to maintain for at least two minutes a lift of at least fifty per cent of the total flying weight.

Models Nos. 5 and 6, having thus proved their readiness for trial in flight, were accordingly, in April, 1899, taken to Chopawamsic Island, together with the old " overhead " launching apparatus and the new one above described, and placed on a small house-boat similar to the one which had been used in 1896. Two men were detailed for this special work, and were first employed in mounting the old launching apparatus for a few preliminary tests with it, in order to make sure that the aerodromes were in proper working order before trying them on the new " underneath " one. After considerable delay, due to various causes, this apparatus and the aerodromes were got into proper working condition, and during June, July and August the following flights were made with these machines, the record being condensed from the reports made by the writer to Mr. Langley while he was abroad.

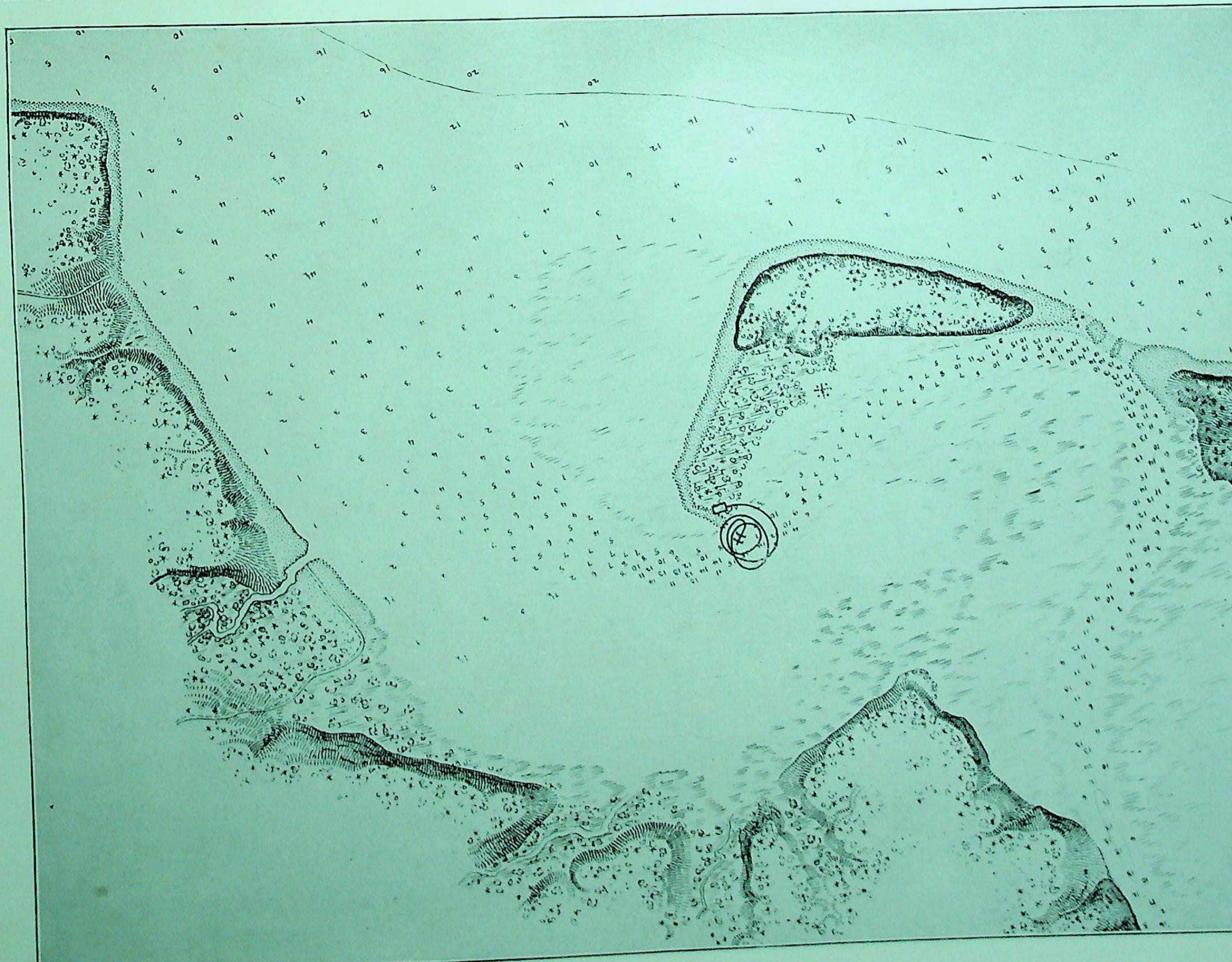
Condensed Record of Flights of Aerodromes Nos. 5 and 6 from June 7 to August 3, 1899

June 7—Aerodrome No. 6

After making a preliminary test of the engines and boiler, with the aerodrome mounted on benches inside the house-boat, to insure that everything connected with the power plant was in proper working order, the aerodrome was mounted on the launching apparatus on top of the house, the various parts were assembled and everything made ready for a flight. As it was calculated that this aerodrome would require a soaring speed of something like twenty-five feet a second, the springs which furnished the motive power for the initial acceleration of the car were adjusted to the proper tension to cause it to reach a speed of approximately twenty-three feet a second at the moment of launching. Everything being in readiness the burners were lighted but worked somewhat sluggishly at first, so that two minutes were consumed in raising a steam pressure of 110 pounds. Although this pressure should have been reached within one minute after lighting the burners, and the extra minute which had been consumed had made a drain on the supply of fuel and water which should have

been left for consumption during flight, yet it was thought best to launch the aerodrome, so at 12.37 p. m. the car was released and the aerodrome launched. The launching apparatus worked perfectly; the aerodrome started off smoothly, and immediately after being released from the car it dropped slightly and began to turn to the right. It had been impossible to move the house-boat out into the stream so as to point the launching apparatus directly into the wind, as one end had settled slightly on the muddy beach in consequence of the existing low tide. For this reason it was necessary to launch the aerodrome due south, while the wind, which was very light, was from the north-northeast, and, therefore, blowing on its port quarter. The effect of the aerodrome turning to the right immediately after being launched was that it caused the wind to strike it to an increasing extent on the port side until, finally, it was going directly with the wind. It did not, however, continue in this direction, but kept turning to the right in a circle until it headed directly into the wind, which, now striking the under instead of the upper surface of the wings, immediately caused the aerodrome to rise. It continued circling, making three complete circles of approximately 200 feet diameter, dropping slightly when moving with the wind, but rising when moving against it, until, at the completion of the third circle, it had altered its path to such an extent that the left front wing touched a tree and caused the front of the machine to dip a little. It, however, kept up its flight, but the contact with the tree had so lowered its bow, and apparently also caused the wings to be twisted to such an extent, that it seemed unable to rise again, and after making another quarter circle it descended. Although the propellers were still turning when it struck the water, they had very greatly decreased their speed, making it apparent that the power had been very greatly reduced through the exhaustion of the fuel and water supply. The aerodrome did not sink, but slowly drifted with the current of the creek and was recovered in about five minutes and brought to the house-boat, where the wings were dismounted and dried, and the metal parts were carefully wiped off to prevent them from rusting. The path of this flight is plotted on a portion of a coast-survey chart and is shown in Plate 33.

This erratic circling at first seemed unaccountable, but on closer examination, after the aerodrome had been brought into the house-boat, it was found that the pin which connects the synchronizing gear to the port propeller shaft had been sheared off. This had evidently happened while the aerodrome was still on the launching apparatus. The effect of this was to throw the total work of the water-circulating pump on the starboard engine, thus giving the port engine less work to do, and consequently making the port propeller run much faster than the starboard one, and thereby causing the peculiar and erratic circling of the aerodrome. It is evident that the undulatory motion of the aero-



PATHS OF FLIGHT OF AERODROME NO. 6, JUNE 7, 1899

drome was due to the fact that, when it was moving against the wind, the speed relative to the air was greater than when it circled so as to go with the wind, and that this greater relative velocity increased the lifting power of the aerodrome.

The total time of the flight was 57 seconds, and the distance covered was between 2000 and 2500 feet, thus giving a speed of a little less than 30 miles an hour. Comparing this flight with that of November 28, 1896, made by the same machine, it will be noted that in the earlier flight the velocity was practically the same, but that the time of flight and the distance traversed then were nearly twice as great as in the present case.

A complete record of the details, not only of weight, but also of the position of the wings, the center of gravity, etc., which show the exact condition of the aerodrome when it made this flight, will be found in the appendix (Data Sheet, No. 3).

JUNE 13—AERODROME NO. 6

In the flight of June 7 there was a slight trembling of the aerodrome while it was in the air, and although this was probably due to the fact that the synchronizing gear was out of operation on account of the shearing off of one of the pins which held it, allowing the port engine to run faster than the starboard one, it was thought possible that some of the trembling might be due to the "wind-vane" rudder, which had been added to represent the equivalent of a steering device by which the operator would control the direction of the large machine. It was decided, therefore, to omit the "wind-vane" rudder in the present test, but to test the aerodrome with the same equipment of single-tier wings and Pénaud tail that had been used in the previous flight, the reel and float being moved to bring the *CG* the same as on June 7.

Everything being in readiness, with the launching track pointed south, and the wind blowing only about 5½ miles an hour from the southwest, the burners were lighted and 63 seconds were consumed before the steam pressure rose to 100 pounds. Although the valve which controlled the burner was open to its full extent the pressure showed no tendency to rise above 100 pounds, which was not considered quite high enough to furnish sufficient power for a successful flight, but as it was desired to determine at once at how low a steam pressure the aerodrome would fly successfully, it was decided to launch it even at this pressure. The launching apparatus was accordingly released and the aerodrome started off, gliding down about three feet immediately after being released, and then rising again, turning slightly to the right and then heading directly for the Virginia shore, where it seemed that it would smash itself in the heavy growth of timber, but when it was about 250 feet from the shore it turned towards the right and started back towards the island. The wind, however, which was blowing from its rear, evidently got down the smoke-stack and put out the fire,

for the aerodrome commenced to descend as soon as it turned its back to the wind, and came down in the channel of the creek. The path of this flight is shown by the solid line in Plate 34.

The total distance covered, as measured by plotting the course of its flight on the coast-survey chart, was about 1800 feet, and the length of time of flight was 40 seconds. The aerodrome was immediately recovered and brought into the house-boat, where it was found that there were still about 1000 grammes of water and 100 grammes of fuel unused in it, showing conclusively that the fire had been put out by the wind.

Upon inspection it was found that the aerodrome was uninjured, and although the burner had not worked at all satisfactorily, yet as the weather was exceedingly favorable it was decided to make another trial with it immediately, using the superposed wings.[1]

Everything being in readiness the burners were lighted, and 70 seconds were consumed before the pressure rose to 90 pounds, beyond which it was impossible to make it rise. Although it was felt certain that 90 pounds was not sufficient pressure to furnish the power necessary, yet as a storm was approaching in the distance, it was decided to launch the aerodrome, as it could at least be determined whether it was properly balanced for the superposed wings. When a total of 75 seconds had been consumed the car was released and the aerodrome was launched. The wooden arrangement for pressing down on the top of the wings to keep the aerodrome from being injured by the wind while it was on the car had been raised to the proper height for the superposed wings, but it had not been noticed that the sticks which support this arrangement had been elevated so much that they would come in contact with the beam extending across the boat, and from which the launching track was supported. Just as these sticks reached the cross-beam, however, it was noticed that they projected about three inches above the lower side of it; but the next moment they struck it, and although the force with which the car was running broke all four of them, the blow was sufficient to slow down the car, and thereby cause the aerodrome to be launched at a very greatly reduced speed; not over one-fifth of what it should have been. The shock of breaking these sticks evidently jarred the burners so that the fire was extinguished, for the aerodrome shot forward for about 25 feet and settled with everything intact, and with its mid-rod perfectly horizontal. The aerodrome itself sustained absolutely no injury, coming down as easily as though it had been lowered by a rope, and would have been given another trial immediately but for the fact that it was very late in the afternoon and darkness was rapidly approaching. The data on setting of wings, tail, etc., are shown on Data Sheet No. 4 (Appendix).

[1] These wings are described in Chapter VI, pp. 191.

JUNE 22—AERODROME NO. 6

After several days' delay, due to numerous small but exceedingly annoying troubles,—such as the leaking of boilers because of defects in the copper tubing, and the bursting of the air tank, due to its being pumped up to an excessive pressure, which a defective pressure gauge had failed to indicate,—Aerodrome No. 6 was made ready for another trial, and it was decided to test it again with the superposed wings which had been used in the second experiment of June 13. The aerodrome was mounted on the "overhead" launching apparatus, which it will be remembered had been used in all the previous tests, and after 90 seconds had been consumed in raising a steam pressure of 110 pounds, it was launched directly into the wind, which was due south. After leaving the launching car, the aerodrome flew straight ahead for about 75 feet, when it suddenly turned its bow up into the air at an angle of about 15 degrees, and it seemed that the machine would be blown back onto the house-boat. However, when the rear end of the tail was within about 10 feet of the boat, and only about 10 feet above the water, it suddenly regained its equilibrium and went straight ahead again in the face of the wind with the guy-posts only about 4 feet above the surface of the water, flying almost exactly horizontally for a distance of about 100 feet, when the bow again suddenly became elevated. As the aerodrome was so close to the water, the wind forced it down until the burners were extinguished by coming in contact with the water. This brought the aerodrome to a standstill absolutely uninjured, the propellers being several inches above the water when they quit turning. The aerodrome was brought into the house-boat and thoroughly dried out, and another trial would have been made with it immediately but the wind which had been steadily increasing was now blowing something more than 12 miles an hour, and it was considered best not to attempt experiments in so strong and gusty a wind, for fear of the wings being broken by the wind suddenly veering and striking them on the side or rear while the aerodrome was still on the launching apparatus. The peculiar action of the aerodrome in the air appeared to be due to the fact that the propellers interfered more with the lifting power of the rear superposed wings, as they were then constructed, than they did with the "single-tier" ones. The data on the setting of the wings, tail, etc., are shown on Data Sheet No. 5 (Appendix).

It was also found after the experiment that one of the workmen, in assembling the machine on the launching car, had secretly increased the stiffness of the spring which controls the elasticity of the Pénaud tail. The effect of this increase in the stiffness of the Pénaud tail might at first thought appear to be similar to that of moving the center of pressure forward. Upon a closer analysis, however, it will be seen that the effect is very much greater, as excessive stiffness of the Pénaud tail not only causes the aerodrome to elevate its bow,

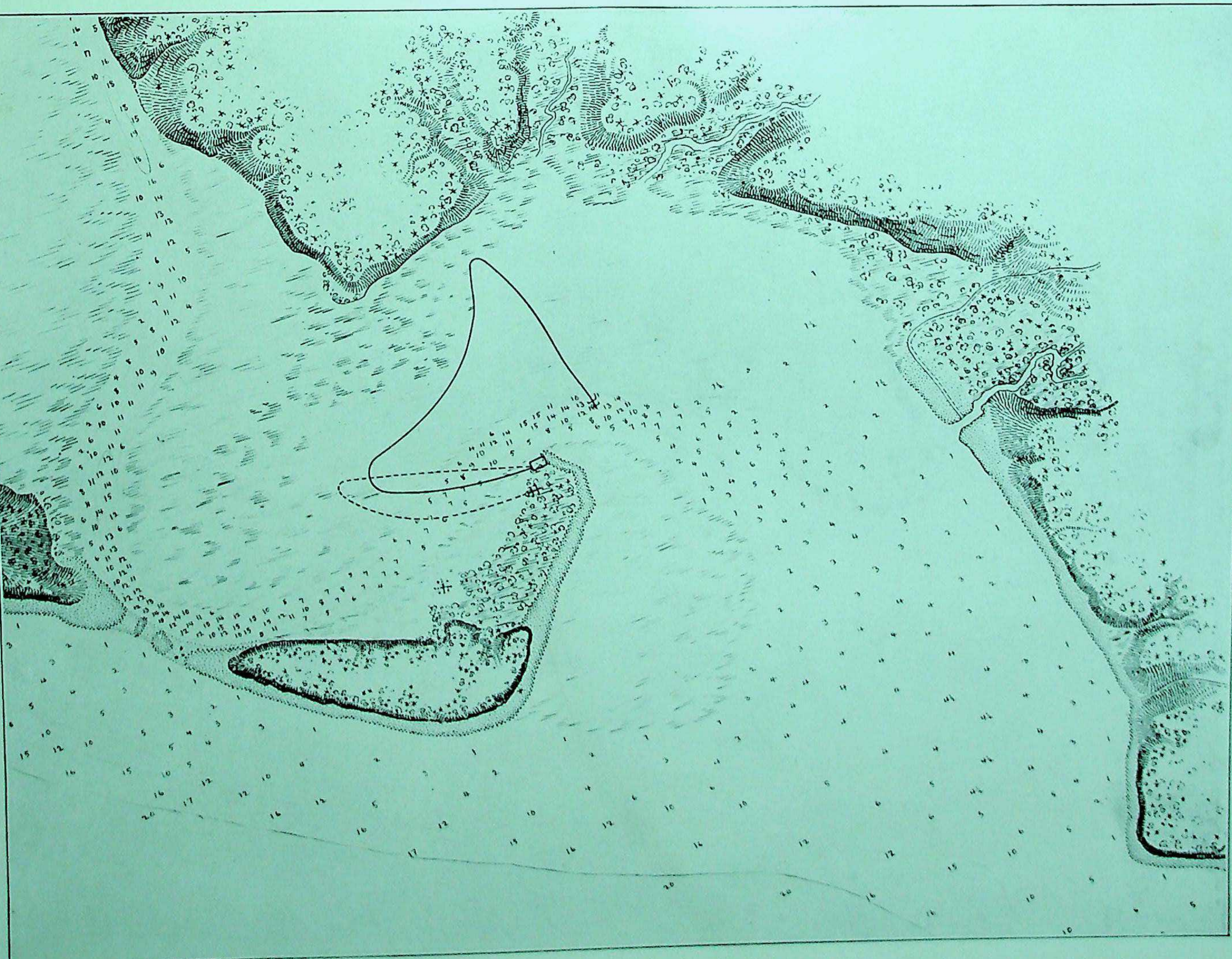
but requires the overcoming of a strong downward force at the rear, even more serious than would be caused by placing an extra load at the rear of the machine without regard to its effect on the balancing. In experiments of this kind, however, the workmen get certain ideas of their own as to how the work should be conducted, and it is almost impossible in assembling the aerodrome to prevent them from making adjustments which are quite different from those which they have been directed to make, and which have been definitely planned with a view to determining the effect of slight changes which it is desired shall not be masked by changes of any kind in other details.

JUNE 23—AERODROME NO. 6

The wind, which had been blowing half a gale all day, gradually quieted down towards sunset and at five o'clock was very light, blowing only two miles an hour from the east-southeast. As one of the rear superposed wings had been injured on the previous day in carrying the aerodrome into the house-boat after its short and erratic flight, it was decided to use the "single-tier" wings in this experiment, and also to continue using the "overhead" launching apparatus for a few more flights. Everything being in readiness, the burners were lighted and 70 seconds were consumed in raising a steam pressure of 120 pounds, at which pressure the aerodrome was launched. It started straight ahead, dropping not more than a foot, and flying on an absolutely even keel for about 800 feet, when it suddenly turned to the left and made a short half circle of about 100 feet diameter, heading for a point about 150 feet east of the house-boat. When it was about 200 feet from the shore, a sudden gust of wind caught under the Pénaud tail, raising the rear portion of the aerodrome and causing the bow to point down at an angle of about 30 degrees. The aerodrome kept this angle and struck the shallow water only about 20 feet from the shore. The aerodrome was comparatively uninjured, and another flight would have been made immediately but for the fact that by the time the aerodrome had been properly inspected it was quite late, and entirely too dark, and there would have been danger of losing it in the adjacent marshes, which are difficult to traverse even under the best conditions of tide and light. The path of this flight is shown by the dotted line in Plate

JUNE 27—AERODROME NO. 5

While the preceding tests had been going on with Aerodrome No. 6, such time as could be spared for it was spent in getting Aerodrome No. 5 into proper condition. The copper tubing from which the boilers for both aerodromes were made was greatly inferior to that which had been used in previous years, and as this tubing could be procured only by having it specially drawn to order in France, and as it required several months after placing an order before the tub-



PATHS OF FLIGHT OF AERODROME NO. 6, JUNE 13 AND 23, 1899

ing could be delivered, it was necessary to make the best of what was already on hand. The copper tubing for the boilers which had been used in 1896, after being carefully annealed and filled with fine sand, could be wound into a perfectly smooth helix, free from all wrinkles, indentations, and so forth, on the inner side of the coil. But no amount of care, both in annealing and in winding this present lot of tubing, would produce a smooth helix, the tubing being badly wrinkled on the inner side of the coil in spite of every precaution. These wrinkles, however, were not so much the cause of serious trouble as was the fact that the tubing was not uniform in quality, each length of it having numerous rotten spots which did not always show up in the winding, but which gave way after the boiler had been completed and one or two preliminary runs in the shop had been made with it. While the effect of such small things cannot be appreciated from merely reading about them, yet they were the cause of the most exasperating annoyance and delay, as no sooner had the aerodrome been gotten into what appeared to be perfect working order than the boiler would break at one or more points, thus causing a delay which at the moment would seem to involve not more than a few hours, but before everything was again in working order would amount to several days.

However, after much perseverance, Aerodrome No. 5 was put in satisfactory working condition, and on June 27 was launched with its "single-tier" wings and Pénaud tail. The data on settings of wings, tail, etc., are given on Data Sheet No. 6. After lighting the burners, 70 seconds were consumed in raising a steam pressure of 120 pounds Immediately upon leaving the launching car the aerodrome started to rise with its bow elevated to an angle of about 15 degrees. It flew straight ahead about 80 feet, when it came backward and downward and touched the water about 40 feet from the boat. The failure of the aerodrome to fly properly was evidently due to its not being in proper balance. The cause of this lack of proper balance was not immediately apparent, but was very soon detected and will be discussed later on.

JUNE 30—AERODROME NO. 5

After several days of incessant rain and strong winds, which prevented an experiment, the weather became brighter and the wind quieted down and the afternoon of June 30 was almost ideal for an experiment. At five o'clock Aerodrome No. 5, with "single-tier" wings and Pénaud tail, was placed on the launching apparatus, a few minutes later the burners were lighted, and just as the propellers started to turn a racking noise was heard. Upon investigation it was found that the circulating pump had broken. The break was a very small matter and could have been repaired in an hour, but it was then too late to repair the damage and get a flight before dark, so the aerodrome was reluctantly dismounted and the men put to work repairing the broken pump.

JULY 1 TO JULY 8

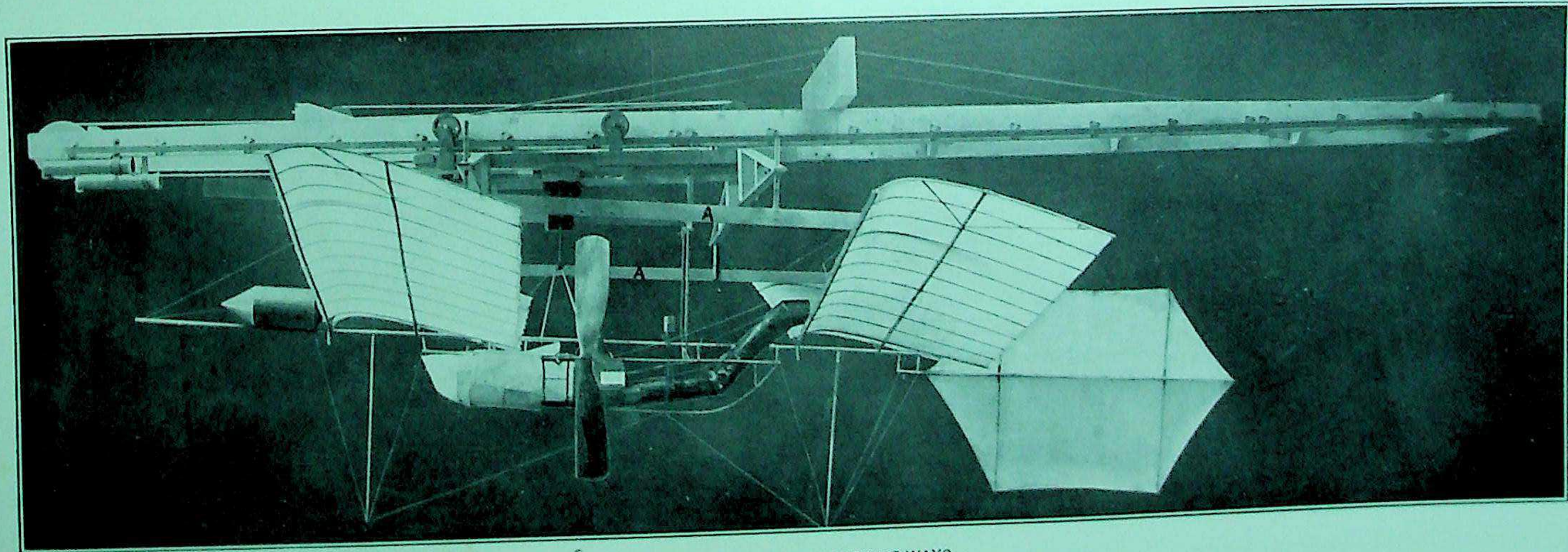
The great disadvantage of conducting the experiments at a point forty miles from the city and the shops was felt at all times. Workmen, even of the very best class, cannot be kept contentedly at work at a point so far removed from their homes, even by bringing them to the city on Saturday afternoon and carrying them back to the experimental grounds the following Monday. Moreover, it is worse than useless to try to get even as much as one-third the ordinary amount of work done if there is the slightest excuse for tightening anchor ropes, watching passing boats, or wasting time on any of the multitudinous small variations from their usual routine of life.

On July 7, Aerodrome No. 5, equipped with "single-tier" wings and Pénaud tail, was made ready for a flight in the afternoon. The settings of the wings, tail, etc., are given on Data Sheet 6. Using the "overhead" launching apparatus, the aerodrome was launched with a steam pressure of 115 pounds. Immediately upon being launched its bow rose to an angle of about fifteen degrees or more, and the aerodrome came backward and downward and touched the water about three or four feet from the house-boat.

It may be well to recall from what has been said in Part I, Chapter IX, that Aerodrome No. 5 is the one with the very low thrust line, and in 1896 had its "separator" several centimetres in front of its center of gravity. When this aerodrome was overhauled just previous to these experiments, the separator was moved back to the same relative position as that in Aerodrome No. 6, so that the gradual depletion of the water supply during flight would not cause it to become light in front of the center of gravity.

In the launching of Aerodrome No. 5, above described, it showed no tendency to drop immediately upon leaving the launching ways, but on the contrary its bow in every case rose almost immediately until it was at an angle of about fifteen degrees or more. From the photograph (Plate 35) it will be noticed that the wings of the aerodrome are held down by the longitudinal strips, *A*, fastened to cross-beams attached to the launching car. If, now, the launching speed is too great and the aerodrome tries to rise immediately upon being released, the front end, which passes from under the launching car before the rear does, and is thus free to rise, will immediately rise, while the rear cannot rise until it has passed entirely in front of the car, which being a distance of several feet requires an appreciable fraction of a second, during which time the bow of the machine has been able to rise to quite a steep angle. This has the effect of slowing down the aerodrome so that it does not get quite the proper chance to start on its flight with a minimum head resistance.

In view of the above facts. it was decided to decrease the speed of the launching car slightly when using Aerodrome No. 5, so that this matter could be thoroughly tested out.



AERODROME NO. 5 ON LAUNCHING-WAYS

Ramesh·
H. (Rameshwer.
Rameshwer
Rameshwer
Rameshwar·
Raghavendra·
Raghavendra·
Sri Ayyar
·A.V.R

JULY 11 TO JULY 14—AERODROME NO. 5

The very early morning preceding actual sunrise on July 11 was undoubtedly as calm as it is possible to find; there was absolutely no breeze stirring and the water in the river was as smooth as glass as far as one could see. The anemometer cups were stationary, the wind vane stood absolutely parallel to the launching apparatus and everything promised a most successful experiment. After mounting the aerodrome on the " overhead " launching apparatus the burner was lighted, and while the steam pressure was still rising and the propellers were revolving faster and faster all the time, there was a snap and they ceased to turn. The fire, which was burning fiercely, ran the pressure immediately to 150 pounds. An attempt was at once made to start the propellers again by giving them an initial turn by hand, it being thought possible that a sudden gush of water had taken place and, accumulating in one end of the engine cylinder, had blocked the engine. However, as the engine refused to keep the propellers going after they were started, and as the pressure was still rising very rapidly, the burner was shut off and an investigation made. Upon removing the hull covering, it was found that the connecting rod bearing had broken off short near the crank pin of the engine, and that it would be necessary to take the part to Washington in order to repair it, as there were no machine tools on the house-boat.

After several days of exceedingly bad weather, the conditions grew more favorable. Late in the afternoon of July 14, Aerodrome No. 5 was again placed on the " overhead " launching apparatus and prepared for a trial. After lighting the burners, 95 seconds were required to raise a steam pressure of 120 pounds. Upon leaving the launching apparatus the aerodrome went directly ahead for a few feet, but immediately commenced to rise, elevating its bow to an angle of 20 degrees by the time it had travelled 40 feet. With its bow in this position, it was blown back towards the house-boat and a little to the right of it, and, when within about 5 feet of the water, suddenly righted itself and started ahead again, rising all the time and reaching a height of about 20 feet by the time it had travelled 100 feet. In the meantime the bow had again become elevated to an angle of about 15 degrees and the aerodrome was blown backwards and downwards again. Just before reaching the water it started to right itself, but it had descended so that the front guy-post was in the water, thus destroying its equilibrium and causing it to settle into the water. The path of this flight is shown by the peculiar S-shaped line in Plate 34.

In the adjustments preliminary to the above trial the Pénaud tail was elevated to an angle of 7½ degrees when the aerodrome was stationary in the shop. This excessive elevation, coupled with the fact that the center of gravity was also probably a little too far forward, no doubt accounts for the erratic flight. The data on setting of wings, tail, etc., are given on Data Sheet No. 7 (Appendix).

JULY 19—AERODROME NO. 5

After several days of exceedingly bad weather the conditions were more favorable on July 19. Since the last experiment on July 14 the coefficient of elasticity of the Pénaud tail had been decreased, the rear wings moved back 5 centimetres, and the "float" so placed that the center of gravity of the machine was brought to the same position it had had on that day, that is, 2 centimetres back of the line of thrust. With this arrangement, assuming that the *CP* is over the *CG*, we should have an apparent efficiency of the rear wings of 63.6 per cent, since the distance between CP_{fw} and CG is 79.7 centimetres, and the distance between CP_{rw} and CG is 125.3 centimetres. With the adjustment of July 14, the distance between CP_{fw} and CG was 79.7 centimetres, and the distance between CP_{rw} and CG was 118.3 centimetres, thus allowing for an apparent efficiency of 67.37 per cent for the rear wings. It will be recalled that in the unsuccessful flight of July 14 the midrod of the aerodrome was inclined at an angle of about 20 degrees during most of the time that it was in the air, thus indicating that the front wings were lifting proportionately more than they should. On July 14 the Pénaud tail had a negative elevation of 7° 30′, and it required 1240 grammes placed at its center to bring it to the horizontal. On July 19 the elevation of the tail was changed to 5° and a weaker spring for controlling the elasticity was substituted, so that it required only 200 grammes placed at the center of the tail to bring it to the horizontal. A rubber band, of about one-half the strength of the upper spring, was attached by means of a cord to the lower guy-post and the lower vertical ribs of the tail, so that the tail would be elastic both ways. This rubber band was in place and acting to help draw the tail down when the above measurement of the coefficient of elasticity was made. A rubber band connected to the lower side of the tail was also used in the flight of July 14, but it was so very weak, compared to the upper spring, that its effect was negligible.

The effect of this change in the balancing of the aerodrome, and also the more considerable effect which the coefficient of elasticity of the tail has on the balancing, will be immediately noticed from the description of the next flight. The data on setting of wings, tail, etc. are given on Data Sheet No. 8.

At 3 p. m., the wind having died down, Aerodrome No. 5, equipped with its "single-tier" wings and Pénaud tail adjusted as above, was placed on the "overhead" launching apparatus. After lighting the burners, one minute and thirty seconds were required to raise a steam pressure of 120 pounds. Immediately upon leaving the launching apparatus, the aerodrome started straight ahead, dropping about 3 feet by the time it had gone 100 feet; it then rose with its midrod at an angle of about 6 or 8 degrees, regaining its level very quickly, however, and making three of these undulations by the time it had gone

300 feet. It continued straight ahead for another 300 feet and began to circle to the left, the diameter of the first circle being about 200 feet. As soon as it started to circle, it rose with its midrod at an angle of about 15 degrees, and by the time it had made its first half turn it started to descend, coming down to within 15 feet of the water. As soon, however, as it had completed this first turn, it again rose, making another half circle, then, upon the completion of this half turn of the second circle, descended, this time to within 10 feet of the water, rising again for the third half turn, but again descending to within 2 feet of the water at the completion of this third circle, and then rising and completing the first half turn of the fourth circle. By this time, however, it had sunk so near to the water that the guy-posts caught in the tall grass while it was descending just before the completion of the fourth circle, thus pulling the aerodrome down into the water with the propellers still running. The total time the aerodrome was in the air was 46 seconds. The total number of revolutions of the propellers was 488, or at the mean rate of 637 R. P. M. Upon examining the aerodrome, after it was recovered, it was found that there were 925 grammes of water left in the separator, the fire having been put out by the aerodrome coming down into the water.

When the aerodrome first commenced to circle during its flight, it was noticed that the front wing clamps had twisted on the midrod, the left wing being dipped downwards, and the right one, of course, being elevated, and the peculiar circling of the aerodrome was undoubtedly due to this fact. The cause of the wing clamp twisting on the midrod was that one of the workmen forgot to tighten one of the screws of the wing clamp when the wings were being adjusted on the aerodrome. But for this unfortunate twisting of the wings, it is probable that the flight would have been perfectly straight and the distance covered would have been considerably greater than it was, the total path traversed being about 2600 to 2800 feet, found by plotting the path on the coast-survey chart and measuring it.

JULY 27—AERODROME NO. 6

As the proper balancing of both Aerodrome No. 5 and No. 6 had now been determined with reasonable accuracy, and as much more time had already been given to the experiments than had been intended, it was decided to dismount the "overhead" launching apparatus at once and substitute the "underneath" one, so that it could be immediately determined whether this newer plan for launching the aerodrome by a car supporting it from underneath would be suitable for use with the large machine. After a considerable period of exceedingly bad weather, during which time the change was made in the launching apparatus, the weather conditions became more favorable on July 27. Aerodrome No. 6, equipped with "single-tier" wings and Pénaud tail, was mounted on the

"underneath" launching apparatus, and everything was got ready for a flight. On lighting the burners, they failed to work properly, and, upon investigation, it was found that the air valve controlling the air pressure on the gasoline tank, was out of order. While this was being repaired, the wind rapidly increased in velocity and became very gusty, thus endangering the aerodrome, as the wings were very liable to be broken by the wind suddenly veering more rapidly than the house-boat could turn or the turn-table could be moved, and thus striking the wings from the side and putting an enormous upward pressure on them, owing to the fact that the diedral angle between them gave to each wing an elevation of 7½ degrees from the horizontal. The aerodrome was accordingly dismounted and everything kept in readiness for a trial, with the hope that the wind would die down, or at least become steady, but it did not do so until after dark.

JULY 28—AERODROME NO. 6

Aerodrome No. 6, equipped with "single-tier" wings and Pénaud tail, was launched from the "underneath" launching apparatus. There was a dead calm, the river not showing a ripple; the wind vane pointed to the northeast, but as the tide was low and the boat was aground, the launching track was pointing due south. At 7 a.m. the burners were lighted, and 80 seconds were consumed in raising a steam pressure of 120 pounds. Everything worked perfectly; the uprights on the car, which initially support the aerodrome and upon its being released are instantaneously pulled down by rubber springs, as well as the disappearing part of the track, acted without the slightest hitch. Immediately upon leaving the launching apparatus, the aerodrome depressed its bow to an angle of between 3 and 4 degrees and made a direct line for the water. At this angle it struck just on the opposite side of the channel, about 300 feet from the house-boat, and while several minor parts, such as guy-posts, were injured no damage of importance was done. Owing to the difficulty of getting through the marsh and recovering Aerodrome No. 6, it was found impossible to make another trial with No. 5 before the wind had increased to a prohibitive velocity. The path of this flight is shown by the dotted line in Plate 36. The data on setting of wings, tail, etc., are given on Data Sheet No. 9.

The last previous trial of Aerodrome No. 6 was made on June 23, and the balancing at that time was evidently correct for the settings of the tail which were then used. The Pénaud tail then had an elevation of 7½ degrees, and the coefficient of elasticity was such that 1240 grammes were required at the center of the tail to deflect it to the horizontal. In the trial above recorded, on July 28, the adjustments of the wings were practically what they were on June 23, the *CG* being moved forward 1 centimetre, but the Pénaud tail had an elevation of something less than 5 degrees, and the coefficient of elasticity was such that

200 grammes placed at the center were required to deflect the tail to a horizontal. It was not intended that the angle of the tail should have been less than 5 degrees, but it was found that one of the workmen had improperly attached the fastening wire, and had considerably decreased the angle. This last adjustment of the Pénaud tail should have been the same as that used on Aerodrome No. 5 in its flight of July 19. The *CG* had purposely been moved forward slightly, but the effect of moving the *CG* forward and at the same time decreasing the stiffness and angle of the tail was shown by this flight.

The above trial not only very clearly emphasizes the importance of carefully determining what the elasticity of the Pénaud tail should be, but also emphasizes the fact that even the best workmen, who have had several years of experience, cannot be relied on in anything which requires that everything be done *exactly right* and not *nearly right*.

JULY 29—AERODROME NO. 5

The aerodrome equipped with "single-tier" wings and Pénaud tail was launched from the "underneath" launching apparatus at 9 a.m., 1 minute and 30 seconds having been required to raise 120 pounds steam pressure. The wind was from the southeast, with a velocity of 3 miles an hour, and the launching track was pointed directly into it.

The launching apparatus, with the disappearing track, worked perfectly, and the aerodrome started straight ahead, dropping slightly at first, but immediately regaining its level and going ahead, gradually raising its bow to an angle of about 8 or 10 degrees, and slightly slacking up its speed by the time it had gone about 300 feet. It then made a circle to the left of a radius of about 75 feet and started back. As soon as it had made this turn it regained its level and directly regained its speed. But as soon as it had speeded up again it elevated its bow, which slackened its speed as before. It then again righted itself, still going in the same direction and crossing the sand-bar on the point of the island at a height of about 40 feet. As soon as it had crossed the sand-bar, it again made a circle to the left with a radius of about 75 feet, heading directly for the house-boat, but when it had got back above the sand-bar it again circled to the left, passing directly between two tall trees, and barely missing them, and still circling to the left, when it again reached the opposite side of the sand-bar. It, however, kept on circling to the left and once more started back towards the house-boat, this time passing to the left of the trees and again barely missing them, and completing this, its second, circle over the sand-bar. It then started due north, heading directly for Quantico, but by this time something had evidently happened to the burners as the fire went out, and the propellers gradually slowed up. However, it kept on towards Quantico, gradually descending on an even keel, and came down in the water at a point about 500 feet

from the sand-bar and about 1000 feet from the house-boat. The propellers had almost ceased turning when the aerodrome came down into the water, and it settled almost as quietly as though it had been picked up and placed there, so that no damage was done to it.

The total time that the aerodrome was in the air was 63 seconds, and the total length of flight was about 2500 feet. The path of this flight is shown by the dotted line with the double circle in Plate 36. The data on settings of wings, tail, etc., are given on Data Sheet No. 10.

As soon as the workmen had had their breakfast, Aerodrome No. 5 was again placed on the launching apparatus, equipped this time with the superposed wings and Pénaud tail. Upon lighting the burners, it was found that they did not work properly, a small piece of soot having clogged up the tip of the vaporizing coil. While this trouble with the burners was being remedied, the wind increased to such an extent that it was found necessary to remove the aerodrome from the launching apparatus to prevent its being injured by side gusts. As it was Saturday and the wind showed no signs of quieting down, the experiments were discontinued until the next week.

AUGUST 1—AERODROME NO. 5

After placing the aerodrome on the launching apparatus and getting everything in readiness for a flight, upon lighting the burners a sudden sheet of flame shot out of the smoke-stack and so seriously charred three panels of each of the rear wings that they had to be removed for repairs. The silk covering of the wings had been coated with a special fire-proofing preparation, but the intensely hot flame, of course, charred all the silk that it came in contact with.

By the time that the wings had been repaired, and the defect in the burner which caused the accident had been remedied, a severe storm had arisen, making it necessary to remove everything to the interior of the boat. While waiting for the weather to become more suitable, a test of the engine of Aerodrome No. 5 was made inside of the house-boat. In this test a steam pressure of 140 pounds was obtained, giving 650 R. P. M. of the round-end, 100-centimetre propellers, which previous tests had shown to mean a thrust of 7480 grammes. As the flying weight of the aerodrome was now 14,104 grammes, the thrust obtained would correspond to a lift of 53 per cent of the flying weight, which was maintained in this test for 90 seconds.

As the *CG* of Aerodrome No. 5 seemed to be a little too far forward in the flight of July 28, it was decided to change it slightly, and it was moved back 4 millimetres.

A trial run in the house-boat was also made on Aerodrome No. 6, while waiting for the weather to become more suitable, but, unfortunately, the result of this test was disastrous. The aerodrome had been placed on trestles and

PATHS OF FLIGHT OF AERODROME NO. 5, JULY 29, 1899

held down to the floor by wires fastened to the cross-frame. In the midst of the test one of the wires slipped, allowing the aerodrome to push forward and thus permitting the propellers to come in contact with the wires which held it to the floor. Both propellers were entirely demolished and the cross-frame was broken off short just at the right-hand engine. The disaster was entirely due to the carelessness of one of the workmen in tightening one of these wires, a further example of the extreme heedlessness of workmen, even in the most important details, which concern the very existence of the machine.

AUGUST 3—AERODROME NO. 5

After the very satisfactory trial of Aerodrome No. 5 in the shop two days previous, it was hoped, now that the weather had become suitable, that a good flight with the superposed wings would be obtained. The aerodrome, equipped with these wings, was accordingly placed on the launching apparatus and the burners were lighted, but they refused to work properly, a steam pressure of only 80 pounds being obtained. After much delay the burners were finally got to work properly, but the wind had increased in velocity to such an extent that it was necessary to remove the aerodrome to the interior of the house-boat. As the wind continued to increase in velocity it was decided to make another trial of the aerodrome inside of the house-boat. Upon doing this it was very soon found that there was a small leak in the front turn of one of the coils of the boiler, and the steam from this played directly against the burner, causing it to work intermittently. A new coil was substituted, and after some adjustment a very excellent run was obtained, the steam pressure reaching 130 pounds and the propellers making 654 R. P. M.

In the afternoon the wind quieted down and the aerodrome, equipped with superposed wings, was again placed on the launching apparatus. The burners were lighted but again refused to work properly, the vaporizing tip being stopped up with soot. This caused the burner to "flood," which sent a sheet of flame through the stack and burned the rear right wing.

A new wing was substituted, the burner tip was cleaned out and everything was again put in readiness for a flight. Upon lighting the burners, 1 minute and 58 seconds were required to raise 120 pounds steam pressure. The underneath launching apparatus, with the disappearing track, worked perfectly, the aerodrome dropping slightly, but going straight ahead. It, however, continued to descend for a distance of about 100 feet, the bow being elevated about 5 degrees. The bow then became horizontal, the aerodrome rising slightly at the same time, but going only about 50 feet farther, when it again started to descend slightly, and finally settled gently on the water between 300 and 500 feet from the house-boat, with its bow elevated about 3 degrees. There was a hiss as the hull touched the water, showing that the fire was still burning and making it im-